International Journal of Scientific Research in Computer Science and Engineering
Vol.**13**, Issue.**3**, pp.**69-75**, June **2025**
E-ISSN: 2320-7639
Available online at: www.isroset.org

Research Article

A Design of Modified Dual-Band Microstrip Patch Antenna for WLAN/WIMAX/SATELLITE Applications

Iliya Danladi Brahim[1*], Iliya Abdullahi Aliyu[2], Auwal Idris Dauda[3]

[1]Dept. of Computer Science, Federal College of Education (Technical) Bichi, Kano, Nigeria
[2]Dept. of Electrical and electronics technology, Federal college of Education (Technical) Bichi, Kano, Nigeria
[3]Dept. of Electrical and Electronic Engineering, Nigeria Defence Academy, Kaduna, Nigeria

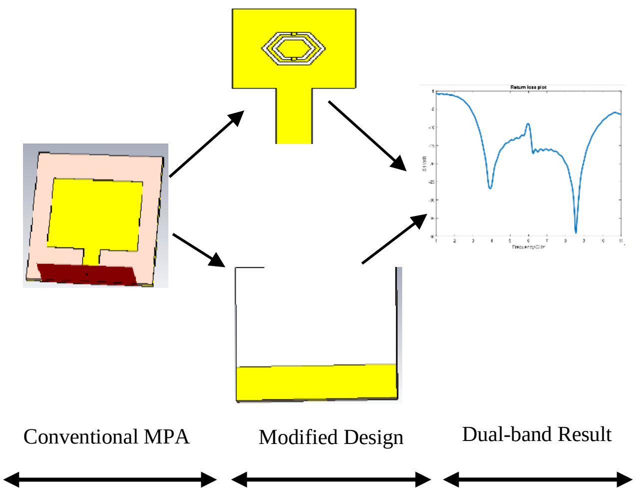
**Corresponding Author:*

Received: 23/Apr/2025; **Accepted**: 24/May/2025; **Published**: 30/Jun/2025. | **DOI**: https://doi.org/10.26438/ijsrcse.v13i3.695

Abstract—This paper presents a modified dual-band MPA (microstrip patch antenna) by incorporating a hexagonal complementary split ring resonator (HCSRRs) on the radiating patch with partially ground plane structure. Numerical simulations are presented using Computer Software Simulator (CST) microwave. The measured result shows that the antenna exhibits dual band resonance with bandwidth of 3.26 – 5.89 GHz and 6.06 – 9.72 GHz at the -10 dB return loss, centered at 4.575 GHz and 7.89 GHz respectively. These bands cover WLAN (Wireless Local Area Network), WiMAX (Worldwide Interoperability for Microwave Access) and satellite communication frequency band. The directivity of the antenna was satisfactory also found to be 3.02dBi, 2.84 dBi in the two frequency bands of operation. The VSWR was found to be 1.044 and 1.096 within the range of operating frequencies. These shows that the antenna has a minimum signal reflection which signify good impedance matching.

Keywords— Hexagonal complementary split ring resonator (HCSRR), Dual-band, Bandwidth, Partial ground plane.

Graphical Abstract



1. Introduction

In modern wireless communication, Microstrip Patch Antennas (MPA) have received considerable research interest due to its moderate performance and ease integration in wireless communication system. The MPA can be made on plane or non-planar using modern printed-circuit technology. The major operational disadvantage of MPA are low efficiency and very narrow frequency bandwidth [1]. However, extending the height of the substrate would improve the efficiency and bandwidth to about 90 and 35 percent respectively, which are not desirable due to the increase in size of the antenna [1]. Recently, the research in wireless communication move toward reducing the size of communication devices, therefore the compactness of radiating elements would be very important [2] . It is therefore, necessary to consider the efficient technique for miniaturization without affecting the performance of the antenna. As such, there is need to find technique for tradeoff between the performance and size of the antenna [3].

Size miniaturization plays vital role in wireless applications but one of the major drawbacks associated with minimizing the size is reducing the antenna bandwidth and gain. It can also shift or create additional frequency bands which result to dual or multiband [4] [5]. Dual band antenna offers advantage of space reduction and help to distribute traffic between two bands. WLAN (Wireless local area network and WiMAX (Worldwide Interoperability for Microwave Access) are major technologies frequently used in mobile and wireless communication. WIMAX-3.5 and 5.5 operates from 3.3-3.8 GHz and 5.25–5.85 GHZ respectively [6]. Also in Satellite communications 3.7 to 4.2 GHz and 5.925 to 6.425 GHz are used for downlink and uplink frequency band respectively [7]. In addition to the inherently disadvantage of MPA, the single patch antenna are used to design antenna for a single application. Due to this limitation, many design techniques have been employed by researchers to enhance the efficient performance of the patch antenna as well as designing the single antenna that can cover the purpose of more than one applications. Therefore, the aim research shift in achieving a tradeoff between the size and performance to meet the goal of wireless applications. This paper present a design of modified dual-band microstrip patch antenna for WLAN/WiMAX/SATELLITE applications. Dual band antenna can operate effectively at two different frequencies. This would enable the single antenna structure to work across two different frequency ranges and also help to create smaller and versatile wireless systems that can perform across multiple frequency bands without needs for multiple antennas this would provide advantage for multi frequency applications. And hence, allows wider coverage, better spectrum utilization especially in environments with high data demand or interference is possible [8].

The propose antenna was designed by etching the hexagonal complementary of split ring resonator (HCSRRs) on the radiating patch. FR-4 was used as the substrate with relative permittivity of 4.3, it was supported by partial ground plane. The proposed work is presented in different sections. The section 1 presents the introduction of the paper. Section 2 present the review of the related literature. Section 3 describes the antenna design and consideration while section 4 present the result and discussion.

1.1 Objective of the Study

The microstrip patch antenna is inherently have operational disadvantage such as poor gain and narrow bandwidth. In addition to poor gain and narrow bandwidth [1]. Conventional patch antenna are used to design for a single application. The objectives of this study is to design antenna that would operate at two different frequency band. This allows antenna to utilize different frequency band for various purposes or applications.

1.2 Organization

The article is organized into the following sections which are as follows; section 1 contains the introduction, section 2 contain the review of the related works, section 3 contains design parameter calculations, section 4 contain the antenna design, section 5 contains result analysis and discussion, while conclusion and future scope comes in section 6

2. Related Work

Conventional MPA suffer from inherent limitations, such as poor bandwidth and gain, and single-band operation, which limit their utilization for wideband or multiband communication systems like WLAN, WiMAX, ISM and WiFi [8]. To overcome these challenges, researchers have proposed several design modifications, including slot incorporation, partial defected ground structures, the use of metamaterials and hybrid mode to improve the antenna's performance parameters. Recently, slot incorporation in MPA designed has been used as a one of the technique used to achieve multi-band frequency or improve the bandwidth of the antenna. In [9] designed a rectangular MPA with inverted U-shaped slot was used to improved bandwidth, enabling it to operate across WiFi and WiMAX bands. Similarly, U-shaped was used to defect the partial ground to achieved dual-band operation. [10] Explore that Metamaterials have been another promising solution for improving the performance of MPA. Metamaterials are artificially fabricated structures and composite materials which gives new response which do not readily available in nature [11]. In [12] the antenna was designed by etching the Complementary split ring resonator (CSRR) help to reduce the size and achieved improved bandwidth of the antenna. Presently metamaterial-based antennas are proposed which uses metamaterial like resonator in the vicinity of radiating patch. Using resonating element like Split Ring resonator parameters of monopole antenna can be engineered to obtain metamaterial multiband antenna operating in wireless communication frequencies for various wireless application [11]. In [13] ground plane was defected using hexagonal shape which help to minimize the antenna size. Dual-band is achieved from 1.3 - 1.8 GHz and also 1.8 - 2.6 GHz, with -6 dB bandwidth of 45 MHz and 65 MHz respectively. In [14] reactive load technique was used to enhance the bandwidth. The antenna has dual band which correspond to bandwidth of 124.6 MHz at 2.4 GHz and 119.8 MHz at 5.2 GHz. [15] Presented a small size quad band antenna operating frequency from 2 GHz – 6 GHz with CSRR is placed at the patch. Quad band microstrip patch antenna were proposed in [16]. Four frequency bands having the bandwidth of 475.1 MHz, 107.3MHz, 207.6MHz and 159MHz were obtained at respective resonance frequencies of 2.7 GHz, 3.8 GHz, 5.4GHz and 5.98 GHz respectively. In [10] design a rectangular microstrip patch antenna has the bandwidth of 3.34 GHz from 4.57 to 7.91 GHz with VSWR less than 2 over the operating frequency range. [8] explored a compact multi-band microstrip patch antenna utilizing a DGS approach. By etching a rectangular defect into the ground plane, they achieved resonance at 2.4 GHz, 3.5 GHz, and 5 GHz, catering to WLAN, WiMAX, and WiFi bands.

While significant progress has been made in improving microstrip patch antennas for WLAN, WiMAX band applications, certain research gaps remain. There is need for optimization to balance gain, bandwidth, and miniaturization in a single antenna structure while maintaining robust performance across the target frequency band [9]. Addressing these gaps is essential for developing antennas that meet the increasing demands of next-generation wireless communication systems. A small size dual band antenna capable of operating within WLAN frequency was designed by cutting C shape on the patch and inverted U shaped grooves from the feedline [18].

3. Design Parameter Calculation

The initial step in designing rectangular patch antenna is to specify the center frequency (f_c), relative permittivity of the substrate (ε_r) and height of the substrate (h).The given dimensions of the antenna is computed using the following equations [1].

3.1 The width of the radiating patch, Wp

The width of the radiating patch, Wp is given by:

$$\omega p = \frac{c}{2fc}\sqrt{\frac{2}{1+\varepsilon r}} \quad (1)$$

Where ωp is the width of the patch, fc is the center frequency = 6 GHz, c= 3 x 10^8 m/s.

3.2 The effective relative permittivity

The effective relative permittivity (εr_{eff}) of the substrate given by the formulae in Eq. (2) when the ratio w/h > 1.

$$\mathcal{E}eff = \frac{1+\mathcal{E}r}{2} + \frac{\mathcal{E}r-1}{2}\left[1+\frac{12h}{\omega p}\right]^{-1/2} \quad (2)$$

Where $\mathcal{E}_{eff}$ is the effective dielectric constant, h is the is the substrate height = 1.59

3.3 Change in length of the patch (ΔL)

$$\Delta L = 0.412\,\frac{(\mathcal{E}eff+0.3)\left(\frac{\omega p}{h}+\ 0.264\right)}{(\mathcal{E}eff+0.258)\left(\frac{\omega p}{h}\ +\ 0.8\right)} \quad (3)$$

3.4 Effective length of the patch

$$Leff = Lp + 2\Delta L \quad (4)$$

3.5 Length of the patch

$$lp = \frac{c}{2fc\sqrt{\mathcal{E}eff}} \quad (5)$$

3.6 Substrate dimension

$$Ls = 6h + lp \quad (6)$$

Where Ls is the substrate length.

$$Ws = 6h + Wp \quad (7)$$

Where Ws is the substrate width.

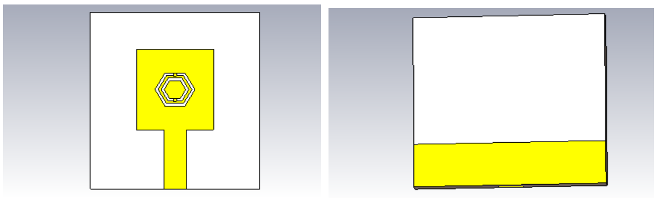
From the values obtained using the adopted equations. The optimization was done using CST MWS. The patch length, width, and the radius of the hexagonal slot positions were optimized to ensure resonance at the desired frequencies and the appropriate dimension of the antenna parameter were tabulated below in table 1.

Table 1: Antenna Parameter

Parameter	Value/Mm
Length of the Substrate, Ls	24
Length of the Substrate, Ws	22
Length of the patch, Lp	11
Width of the patch, Wp	10
Inner radius of the ring, ri	1.4
Outer radius of the ring, ro	2.2
Gap of the split ring, g	0.4
Width of the ring, w	0.3
Thickness of the patch, t	0.035
Width of the feedline, wf	2.93
Length of the feedline, lf	8.0

4. Antenna Design

As seen in Figure1 the proposed microstrip antenna's top view is made up of a rectangular patch that is printed on a substrate that measures 24 mm by 22 mm, is 1.59 mm thick, with relative permittivity of 4.3. Figure 1 (b) depicts a partial ground plane that is positioned on the substrate's bottom. A 50 microstrip line that is 8 mm long and 2.9 mm wide was used to feed the antenna. The top of the radiating patch is where the hexagonal complementary split ring resonator, which has two splits on opposing sides of each ring, is engraved.

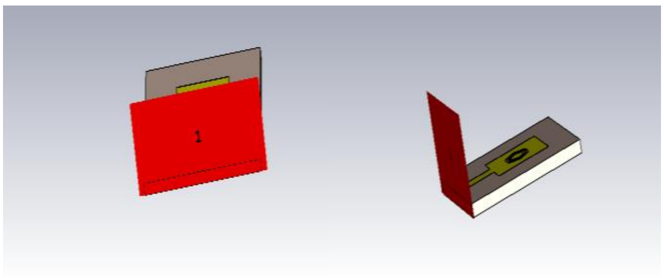


(a) (b)

Figure 1(a) Front view of MPA with HCSSRs (b) Back view of MPA with partial ground plane.

4.1 Port Excitation

Microstrip transmission line requires consideration for waveguide port sizing to ensure the field are properly captured within the port. For open transmission line (microstrip, co-planar, wave guide, and slot line) the wave port must surround the structure. The port width and height must be 5 – 10 times than the width of transmission line and height of the substrate respectively [17].



(a) (b)

Figure 2 (a) Front view of the wave guide port (b) Side view of the wave guide port

5. Results and Discussion

After the simulation, the parameters of the antenna such as return loss plot, gain, directivity plots were extracted from CST software tool and are plotted in the respective figures and tables below.

5.1.1 S-Parameter

The reflection coefficient or return loss (S11) refers to the power reflected back toward the transmitter due mismatch between antenna and the transmission line. At -10dB at least 10% of the transmitted power is reflected back while 90% is absorbed [1]. The proposed antenna was designed, having dual band is potentially a trade-off between an acceptable return loss values below -10dB level as shown in figure 3. The antenna exhibits a dual band resonance with -10 dB impedance bandwidth of 2.36 GHz (3.23 – 5.59 GHz). Similarly, the second band cover 3.82 GHz (5.87 – 9.69 GHz). The minimum return loss at -37.5 and -38.1 was achieved.

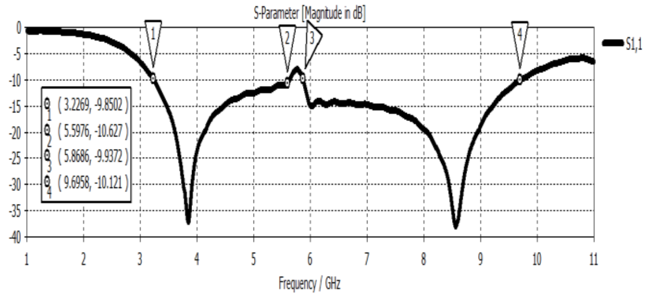


Figure 3: Variation of reflection coefficient with frequency

The VWSR plot of the antenna shown figure 4 has the values lied very close to one at each frequency band of 1.044, 1.096. This indicates a perfect impedance match which means the system has minimum signal reflection and maximum power transfer.

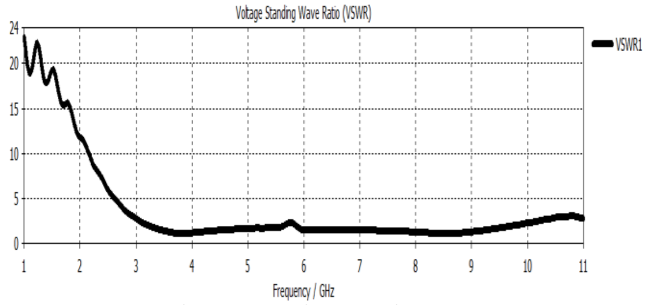


Figure 4: Variation of VSWR with frequency for hexagonal slot antenna

5.1.2 Antenna Gain and Directivity

Both gain and directivity focuses on antenna radiated power but differ in the scope. The directivity describes the antenna's ability radiate a power in a specific direction. While the gain measure both directivity and the antenna efficiency [1]. At 3.5 GHz, the antenna is radiating at 162.0 degree, with the gain of 1.37dB and directivity of 3.03dBi as shown in the figure 5 and 6.

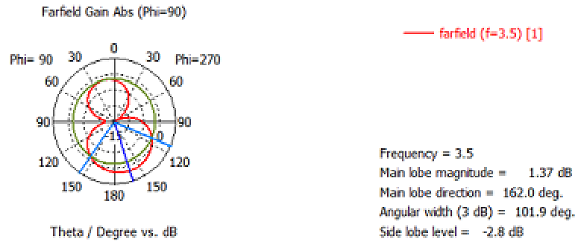


Figure 5: Polar plot of Gain for antenna with hexagonal slot at 3.5GHz

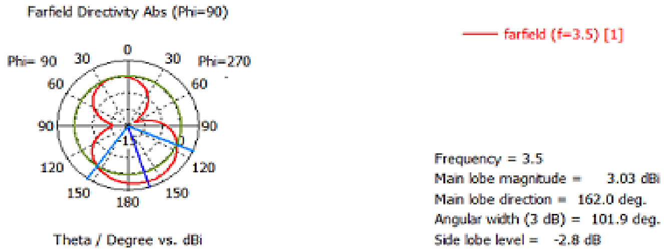


Figure 6: Polar plot of Directivity for antenna with hexagonal slot at 3.5GHz

While the gain at 5.5 GHz has the main lobe direction of 161.0 degree with the gain of 1.64 dBi and directivity of 2.86 dBi as shown in the figure 7 and 8

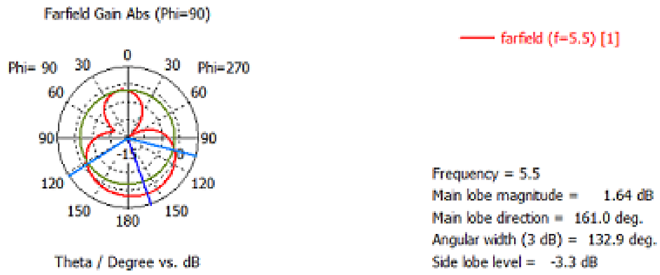


Figure 7: Polar plot of Gain for antenna with hexagonal slot at 5.5GHz

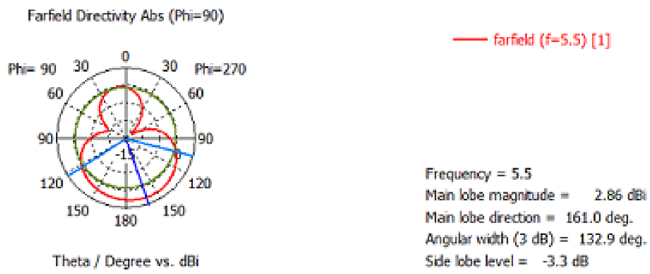


Figure 8: Polar plot of Directivity for antenna with hexagonal slot at 5.5GHz

5.1.3 Radiation Pattern of the Antenna

The E-field and H- field of the antenna describes how antenna radiate and received electromagnetic waves. It define radiation and polarization pattern. If the E-field is vertical, the antenna is consider vertically polarized, and vice versa [1].

Figure 9 and 10 shows farfield E field at 3.5 GHz and 5.5 GHz respectively. While 11 and 12 shows farfield E field at 3.5 GHz and 5.5 GHz respectively.

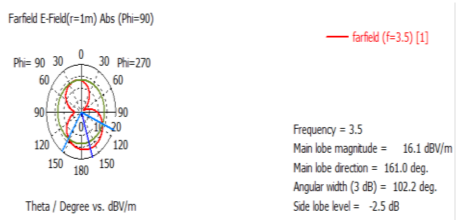


Figure 9: Polar plot of E-Field at 3.5GHz

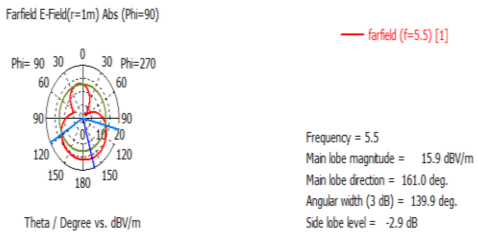


Figure 10: Polar plot of E-Field at 5.5GHz

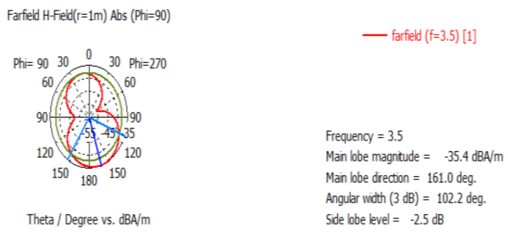


Figure 11: Polar plot of H-Field at 3.5GHz

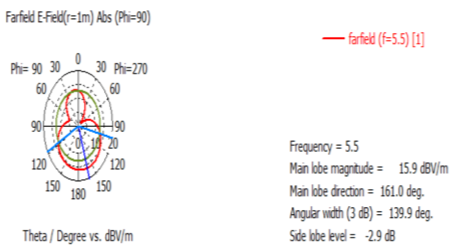


Figure 12: Polar plot of H-Field at 5.5GHz

5.2 Discussion

Table 2 show a comparison between the propose work and existing work. It can be seen in [18] has the resonance frequency of 3.32-362 GHz and 4.72-6.83 GHz cover the bandwidth of only 0.03 GHz and 2.11GHz. While the proposed model operate in dual band, from 3.26–5.89 GHz and 6.06–9.72 GHz with the total bandwidth of 2.63 GHz and 3.6 GHz respectively. Therefore, the dual-band frequency provide advantage for multi frequency applications to operate on a single antenna structure. The VSWR was found to be 1.044 and 1.096 within the range of operating frequencies. These shows that the antenna has a minimum signal reflection and maximum power transfer as compare to the existing design [20].The gain and directivity are related to each other by the efficiency of the antenna. The directivity was found to be 3.02dBi and 2.84 dBi and the gain 1.28 dBi and 1.47 dBi for operating frequency respectively.

As the proposed designed achieved dual band, it demonstrate capability for multi band applications. There is need to meet broader frequency coverage which enable the antenna to operate as wideband or ultra-wideband. This can be achieved by optimizing the antenna geometry, incorporating the novel feeding techniques [1]. The future study need to concentrate on improving the accuracy of the antenna gain. This can be achieved by using array configuration to increase the number of patch element, incorporating parasitic elements, use of metamaterials, optimizing the dimension of radiating patch and substrate or introduction of air gap between the patch and substrate also improve the gain [21].

Table 2: Comparative analysis of the proposed work and existing literature

Proposed Design		[20]
Dimension	32 x 32 x 1.59 mm^3	70 x 60 x 1.6 mm3
Resonance Frequency	3.23 – 5.59 GHz, 5.87 – 9.69 GHz	3.32-362 GHz, 4.72-6.83 GHz
Bandwidth	2.36 GHz,3.82 GHz	0.03 GHz2.11GHz
Directivity	3.03dBi, 2.86 dBi	NA
Gain	1.37 dBi, 1.64 dBi	2.77 dB, 3.34dB
WSWR	1.044, 1.096	1.92, 1.22
S11	-37.5 dB, -38.1 dB	-5 dB, -20.5213

6. Conclusion and Future Scope

This paper introduces the design of a dual-band microstrip patch antenna with a modified structure and operate efficiently within the frequency range WLAN, WIMAX and Satellite applications simulated using CST microwave studio. The modification involves etching the complementary hexagonal split ring resonators (CHSRRs) from the radiating patch and situating them on a partially ground plane. This alteration results in the antenna exhibiting dual-band characteristics, specifically spanning frequencies of 3.23 GHz to 5.59 GHz and 5.87 GHz to 9.69 GHz, while maintaining a reflection efficient of more than -10dB. In the first and second frequency bands the antenna shows a lower reflection coefficient of -37.5dB and -38.1dB, this implies better impedance matching and minimum power loss or signal reflection. The VSWR was found to be 1.044 and 1.096 within the range of operating frequencies. This antenna is well-suited for applications in wireless communication systems that require coverage of both WLAN, WiMAX and satellite frequency band. This paper introduces the design of a dual-band microstrip patch antenna with a modified structure and operate efficiently within the frequency range suitable for WLAN, WIMAX and Satellite applications simulated using CST microwave studio. The modification involves etching the complementary hexagonal split ring resonators (CHSRRs) from the radiating patch and situated on partial ground plane. This alteration results in the antenna exhibiting effective dual-band performance, good impedance matching characteristics and compactness. The antenna operate effectively spanning frequencies of 3.23 GHz to 5.59 GHz and 5.87 GHz to 9.69 GHz, while maintaining a reflection efficient of more than -10dB. In the first and second frequency bands the antenna shows a lower reflection coefficient of -37.5dB and -38.1dB, this implies better impedance matching and minimum power loss or signal reflection. The VSWR was found to be 1.044 and 1.096 within the range of operating frequencies. This indicates that the antenna has less signal reflection and maximum power transfer. This antenna is well-suited for applications in wireless communication systems that require coverage of both WLAN, WiMAX and satellite frequency band.

The future study need to focus on improving the accuracy of the antenna gain. This can be achieved by using array configuration to increase the number of patch element, incorporating parasitic elements, use of metamaterials, optimizing the dimension of radiating patch and substrate or introduction of air gap between the patch and substrate. To meet the demand for the next generation of wireless systems, further research can be further expanded to produce a reconfigurable, multiple-input multiple output (MIMO) antenna.

Acknowledgements: The authors are grateful for the quick review and valuable comments from the reviewers that improved the quality of the manuscript.

Funding Source- No funding is provided from any source from the beginning to the end of this study.

Authors' Contributions-

Iliya Danladi Ibrahim has come up with the research idea also planned the methods used. He is also contributed in writing the manuscripts

Iliya Abdullahi Aliyu: He contributed in research gap finding and coducted the literature review.

Auwal Idris Dauda: Helped in writing the manuscripts

Conflict of Interest- There is no conflicts of interest as declared by the authors.

Data Availability- The data used in the research work was computed by selecting the centre frequency (f_c), relative permittivity of the substrate (ε_r) and height of the substrate (h) to obtain and perform optimization on the antenna parameters as tabulated in Table 1.

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AUTHORS PROFILE

Iliya Danladi Brahim was born in Kano state, Nigeria. He earned his B. Eng. in computer engineering and M. Eng. communication engineering from Bayero University, Kano in 2015 and 2022 respectively. In 2017 he emerged among the winner of National Information Technology Development Fund (NITDEF) scholarship. He is currently working as a lecturer in Department of computer Science from Federal college of Education (Technical) Bichi, Kano Nigeria. His major area of Research interests are antenna design and wireless sensor networks.

Iliya Abdullahi Aliyu was born in Kano state, Nigeria. He earned his B. Eng. In Electrical Engineering from Kano University of Science and Technology, in 2017 Wudil. And currently pursuing M. Eng. in communication Engineering in University of electronics Science and Technology of China. He is also working as a lecturer in Department of electrical and electronics technology from Federal college of Education (Technical) Bichi, Kano. He has published more than 3 research papers in reputed international and local journals and conferences. His main research work focuses on deep learning and Integrated Sensing and Communication. He has 5 years of teaching experience and 6 years of research experience.

Auwal Idris Dauda was born in Kano State, Nigeria. He graduated from Bayero University Kano in 2015. He is currently pursuing M Eng. degree in electrical and electronics engineering at Nigerian Defence Academy Kaduna, Nigeria. He is also working with Sokoto energy research centre, Energy commission of Nigeria.entre, Energy commission of Nigeria.

