



Design of a Modified Wideband Microstrip Patch Antenna for WLAN/WiMAX Applications

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Abstract

This work presents the design of modified wideband Microstrip Patch Antenna with defected hexagonal slot on partial ground plane. The radiating was clipped to form a notch using three different steps to achieve wide impedance bandwidth. At each step of development numerical simulations are presented using CST Microwave Studio (CST MWS) and various performance parameter of the antenna were noted. The proposed design attains a wide impedance bandwidth of 2.97–7.53 GHz with return loss of less than -10dB. The VSWR is between 1 and 2 across the resonance frequency with the minimum value of 1.14 at 3.648 GHz indicating minimal reflection and efficient power transfer. At 3.5 GHz, the antenna exhibits a main-lobe directivity of 2.95 dBi and a gain of 2.28 dB. These values indicate near-omnidirectional coverage with sufficient gain, making the antenna appropriate for WiMAX systems. At 5.5 GHz, the design introduces a directivity of 3.4 dBi and a gain of 2.81 dB. The improved directivity and gain at this higher frequency suggest better radiation and focusing a higher efficiency, which are desirable for WLAN applications such as indoor wireless networking, also this design enhanced the antenna throughput and minimized the interference.

Keywords: Microstrip Patch Antenna, Wideband, WLAN, WiMAX, Notch, Impedance Bandwidth, Compact Size.

1.0 Introduction

The growth wireless communication has placed a much demand in wireless communication technologies because of the need for reliable, high-speed and wideband communication systems. To meet this demand various configuration of the antenna was designed. For an application where size and weight are needed. Printed patch antennas have been the preferred as a better choice over other types of antennas. Microstrip Patch Antennas (MPAs) have attracted research interest because of its ease integration and moderate performance in wireless communication system [1]. However, the major operational disadvantage of this antenna includes narrow bandwidth, low gain, and single-band operation, which restrict their performance in multi-frequency systems [2]. However, this limitation can be overcome by increasing the substrate height which improve both efficiency to 95% and 35% respectively, which are not necessarily due to antenna size increment [3]. Recently, the research in wireless communication shifted toward miniaturizing the communication devices. It is necessary to study the proper method for miniaturization the antenna without compromising its performance. As such, efficient technique is required to balance between the size and performance of the antenna [4]. To achieve tradeoff between the bandwidth, gain and size. Several methods were used to improve the performance of the design, such as increasing the thickness of the substrate, use superstrate, parasitic element, partial ground structures, offset feeding, inset feeds, coupling feeds, addition of slot either radiating patch or ground [5]. This aim in design of single antenna that works in wideband frequency range which help in creating flexible wireless device that work across wide frequency bands.

Wideband systems are highly susceptible to electromagnetic interference because multiple narrowband that often operate in close proximity, making interference mitigation a critical consideration. For example, although a UWB antenna operates over a broad frequency range of 3.1–10.6 GHz, many applications do not require the overall spectrum. Within this range certain narrower frequency bands may be considered sources of interference. WiMAX systems, which operate between 3.3 and 3.8 GHz, may experience interference from WLAN systems functioning in the 5.15–5.825 GHz band. To suppress unwanted signals and ensure proper system performance, a wideband antenna designed to cover the required frequency range while incorporating specific band-notch characteristics is therefore necessary [6].

Many modifications can be used significantly enhance bandwidth, gain, efficiency and making the antenna suitable for wideband operation which can cover WLAN, WiMAX, and ISM frequency band. (WLAN), (WiMAX), and (WiFi) Networks provides seamless connectivity in both rural and urban area (Ali et al., 2020). WLAN operates 2.4 GHz - 5 GHz frequency bands, while WiFi utilize broader spectrum ranges, including 2.5 GHz - 3.5 GHz and

higher frequencies [7]. WiMAX provide internet access and high-speed data rates over wide area. WIMAX 802.16 standard operates at three different licensed bands 2.3-2.69 GHz, 3.2-3.8 GHz and 5.2-5.8 GHz [8].

Flexible and wearable implementations of notched wideband antennas show how defected ground structures (DGS) and shaped slots can realize stable notch behavior. [9] designed a flexible Kapton-based UWB antenna that used two triangular spiral slots in the ground plane to produce dual notches. One rejecting WLAN/WiMAX, another rejecting Hyper-LAN/2 importantly, the antenna retained acceptable performance when bent, demonstrating that notch implementations can be robust to realistic form-factor constraints [9].

For instance, incorporating slots or DGS enables better impedance matching and multi-band operation [10], while metamaterials offer improved radiation performance [11]. Multiple resonance frequency was achieved by incorporating slot on the metallic radiating patch [2]. Recent finding has shown that combining multiple techniques by incorporating slots and defected ground structures improve antenna performance enabling multiple resonance at WLAN, WiMAX, and WiFi frequencies [12]. [13] also designed two notches of the same size loaded on top of the patch to enhance the bandwidth and gain of the antenna. A coaxial feed square microstrip patch antenna with the truncated corner is designed to achieve dual band [14]. [15] combined an elliptical slot and splitting resonators with a DGS to obtain independently tunable notches while preserving a very large passband.

Split-ring resonators (SRR) and complementary SRRs (CSRR) are widely used to produce high-Q notches with relatively small physical footprint. These resonant inclusions can be placed on the patch, in a parasitic layer, or in the ground plane. This can provide a control of the notch frequency and depth with limited impact on the broadband matching if coupling is carefully tuned. [16] illustrated how SRR arrays tuned resonance control and bandwidth in a wideband. Despite the fact that, achievement recorded in design of MPAs for wideband applications, there is certain research gaps remain. Therefore, there is need for optimization of the certain parameter to balance gain, bandwidth, and size in a single antenna structure [12]. To address these gaps is need to develop antennas that meet the demands of future wireless communication systems.

The objective of this study is to design and simulate a modified wideband microstrip patch antenna that addresses the limitations of conventional designs. The proposed antenna aims to provide wideband operation covering the key frequencies ranges for WLAN, WiMAX [8] and ISM band applications, specifically at 3.5 GHz, and 5.5 GHz. However, in this work, the defected hexagonal slot on partial ground plane and the notch using three different steps were introduced in the design in order to improve wide impedance bandwidth. Through careful design, optimization and simulation using CST software tools, the study evaluates critical performance metrics such as return loss, gain, bandwidth, and directivity.

2.0 Antenna Design and Consideration

The dimension of the MPA can be obtained by considering the resonance frequency (f_r) of the antenna. The mode details and the size of the patch and substrate are calculated below. Therefore, the adopted equations provide the necessary mathematics model involved in the design of MPA [3].

2.1 Design Parameter

The first step in designing rectangular MPA is to select the resonance frequency (F_r), dielectric constant (ϵ_r) and height of the substrate (h). Different parts of the antenna were computed using formulae below [3].

The width of the patch (W),

$$W = \frac{V_o}{2F_c} \sqrt{\frac{2}{1 + \epsilon_r}} \quad (1)$$

where W is the width of the patch element, F_c is the center frequency = 6 GHz, V_o is the velocity of light = 3×10^8 m/s, ϵ_r is the dielectric constant of the substrate material (FR-4) = 4.3.

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

$$\epsilon_{eff} = \frac{1 + \epsilon_r}{2} + \frac{\epsilon_r - 1}{2} \left[1 + \frac{12h}{W} \right]^{-1/2} \quad (2)$$

where ϵ_{reff} is the effective dielectric constant, height of the substrate materials $h=1.59$

Change in length of the patch (ΔL)

$$\Delta L = 0.412h \frac{(\epsilon_{eff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{eff} + 0.258) \left(\frac{W}{h} + 0.8 \right)} \quad (3)$$

Effective length of the patch

$$L_{\text{eff}} = L + 2\Delta L \quad (4)$$

Length of the patch

$$L = \frac{V_0}{2F_c \sqrt{\epsilon_{\text{eff}}}} - 2\Delta L \quad (5)$$

Substrate dimension

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

where L_s is the length of the substrate.

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

Where W_s is the width of the substrate

2.2 Conventional Microstrip Patch Antenna

Figure 1 shows the top and back view of conventional rectangular MPA. The antenna was designed on FR4 substrate with relative permittivity (ϵ_r) of 4.3 and height (h) of 1.59 mm of area of 32 x 32 mm². The metallic patch at the top layer with the dimension 23 x 17.5 x 0.035mm³ was placed on a substrate. A 50 Ω fed line is used on the edge of the top patch to excite antenna. The optimize dimensions of the conventional antenna were shown in Table 1.

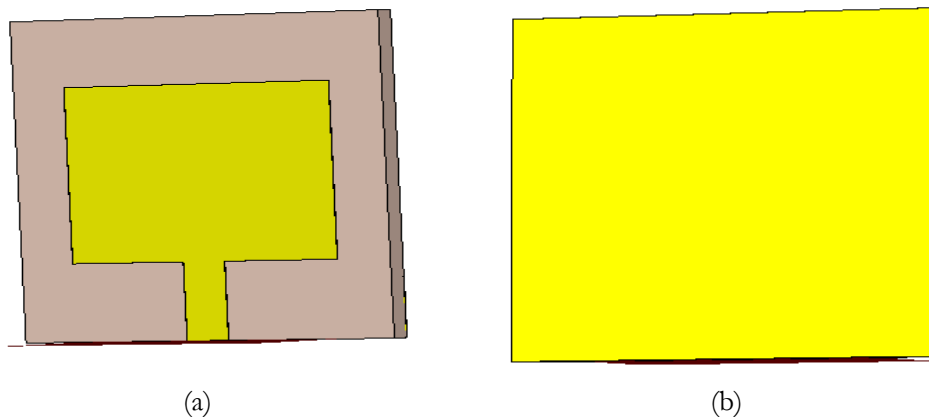


Figure 1: Geometry of the conventional MPA (a) Top view (b) Back view

Table 1: Antenna Parameter

S/N	Parameters	Values (mm)
1	Inner radius of the hexagonal ring, r_0	2
2	Length of the substrate, L_s	32
3	Width of the substrate, W_s	32
4	Length of the patch, L_p	17.5
5	Width of the patch, W_p	23
6	Width of the hexagonal ring, w	0.2
7	Center frequency, f_c	6 GHz
8	Width of the ring, w	0.2
9	Gap of the split ring, g	0.4
10	Height of the substrate, h	1.59
11	Thickness of the patch, t	0.035
12	Width of the feedline, w_f	3.6

2.3 Design with Partial Ground Plane

The length of the ground plane of the conventional microstrip patch was reduced to a partial ground plane as depicted in Figure 2. The parametric sweep was used to observe the effect of the change in length from 7mm to 5mm at the step of 1mm. The return loss plot was observed at each stage. The best value was obtained when the length was reduced to 6 mm.

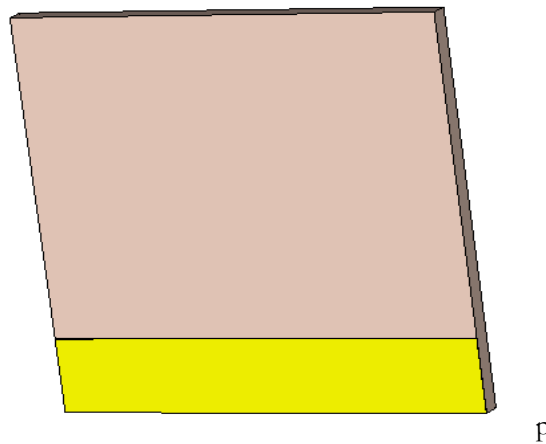


Figure 2: Structure of Partial Ground Plane

2.4 Modification of Antenna using Defected Ground and Notch

The partial ground plane was defected with a hexagonal slot. Analysis was done to study the optimum value of the partial ground plane and the width of the hexagonal ring. Various steps of the notch were studied by cutting the bottom edge of the two sides of the radiating patch as shown in Figure 3 and 4. In each stage, the performance of the antenna was studied.

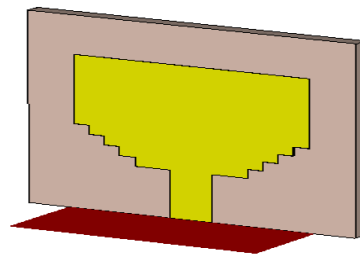


Figure 3: Front view of the Modified Antenna

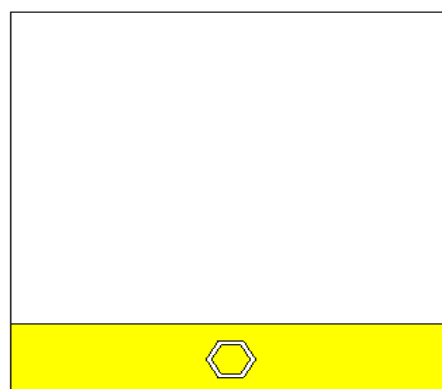


Figure 4: Back view of the Modified Antenna

3.0 Results and Discussions

This section presents the result of the simulation carried out in computer simulation technology (CST) microwave studio suite 2016. The parameters such as return loss (S_{11}), bandwidth, directivity and the gain were noted.

3.1 Results of Conventional Microstrip Patch Antenna Design

The reflection coefficient curve (S_{11} plot) represent the reflected power from the antenna. For efficient operation of the antenna, the return loss must to be less than -10dB for a specific frequency of operation. When $S_{11} = -10$ dB, it means that 3 dB of power is supplied to the antenna and -7 dB is reflected. Figure 6 shows reflection coefficient of the antenna at -10dB were found between 5.80 — 6.19 GHz (390 MHz) and the value of VSWR is between 1 -2 within the resonance frequency as shown in Figure 5 and 6.

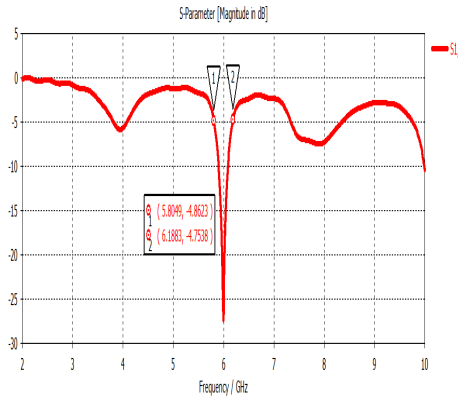


Figure 5: Return loss plot of conventional design

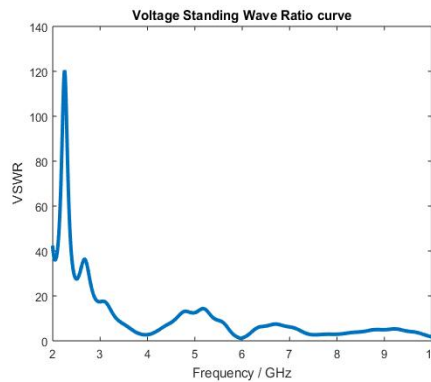


Figure 6: VSWR plot of conventional design

3.2 Parametric Sweep of MPA with Partial Ground Plane

In order to improve the bandwidth of the conventional antenna parametric sweep was conducted on the ground plane of the MPA. The partial ground plane was varied from 5 to 7 mm at step size of 1, while keeping other antenna parameters unchange. The sweep shows that reducing the ground plane dimension significantly affects the antenna’s electromagnetic behaviour, such as resonant frequency, return loss (S_{11}), and bandwidth, gain. At a length 7mm, the antenna exhibited impedance matching, which result in higher reflection losses as shown in figure 7. The bandwidth span from 3.11 to 4.98 GHz.

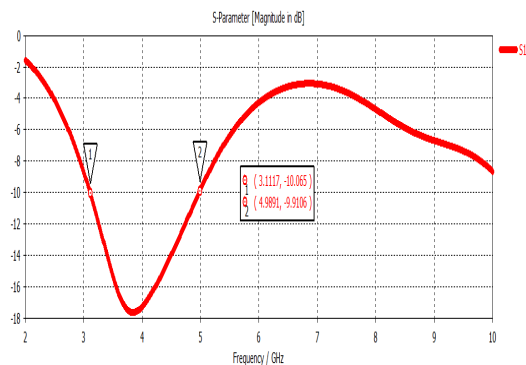


Figure 7: Return Loss Plot of the antenna partial ground plane at length of 7mm

Figure 8 shows the lowest return loss of -24dB and improved bandwidth of 2.87 to 5.17 by setting partial ground plane to 6 mm.

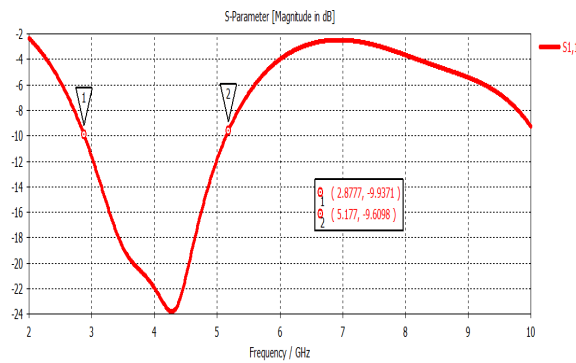


Figure 8: Return Loss Plot of the antenna partial ground plane at length of 6mm

Further reduction of partial ground plane to 5mm caused performance degradation, which cover the impedance bandwidth of 2.71 to 5.03 GHz.

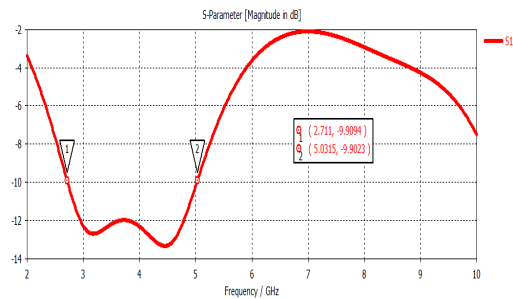


Figure 9: Return Loss Plot of the antenna partial ground plane at length of 5mm

Reducing partial ground plane to 4.5 mm causes impedance mismatch. The antenna resonate at two different frequency 2.6 to 3.5 and 3.8 to 4.9 GHz as shown in Figure 10.

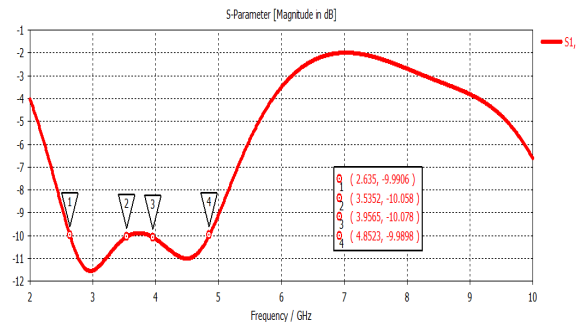


Figure 10: Return Loss Plot of the antenna partial ground plane at length of 4.5mm

Therefore, the results show that the optimal antenna performance occurs at a length of partial ground plane of 6mm, where minimum return loss and improved impedance matching were achieved.

3.3 Effect of the Width of Hexagonal Slot on Partial Ground Plane

The width of the hexagonal slot etched on the partial ground plane has a significant influence on the impedance bandwidth antenna. Analysis was performed by varying the slot width from 1.2 to 0.2 mm. For a slot width of 1.2 mm design antenna exhibits an impedance bandwidth of 1.4 GHz and 1.29, operating from 3.22 – 4.62 GHz and 5.96 - 7.25 mm.

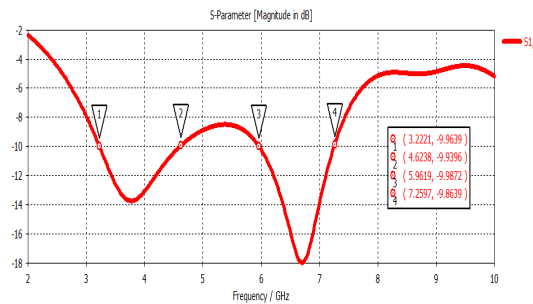


Figure 11: Return Loss Plot of the antenna with defected partial ground hexagonal ring of width 1.2 mm

By decreasing the width of the ring to 1 mm, the return loss indicate improvement in the value of the reflection coefficient at -26.67 dB.

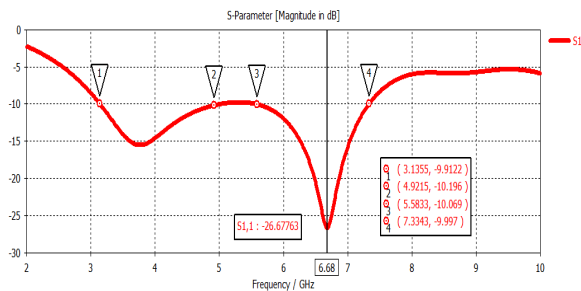


Figure 12: Return Loss Plot of the antenna with defected partial ground hexagonal ring of width 1 mm

As the slot width is decreased to 0.8 mm, a notable improvement in impedance matching is observed. Dual band plot is changing to a relatively wideband.

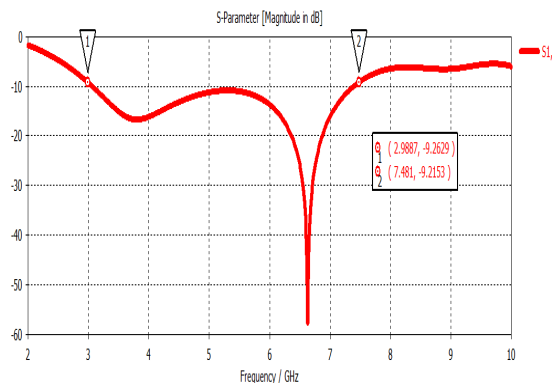


Figure 13: Return Loss Plot of the antenna with defected partial ground hexagonal ring of width 0.8 mm

Decreasing the slot width of 0.6 mm, the antenna achieves a significantly enhanced -10 dB impedance bandwidth of 4.5 GHz, covering the frequency range of 2.98 – 7.48 GHz, with a minimum S₁₁ of -22.17 dB.

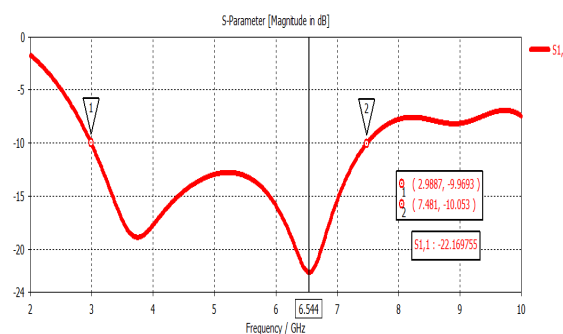


Figure 14: Return Loss Plot of the antenna with defected partial ground hexagonal ring of width 0.6 mm

Furthermore, reducing the width to 0.4 mm, the antenna achieves impedance bandwidth of 4.52 GHz, covering the frequency range of [3.00 – 7.52 GHz], with a minimum S₁₁ of -21.68 dB.

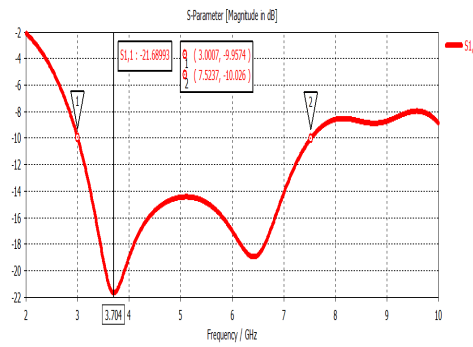


Figure 15: Return Loss Plot of the antenna with defected partial ground hexagonal ring of width 1.2 mm

Further reduction slot width to 0.2 mm increases facilitates the excitation of additional resonant modes, which contributes to bandwidth enhancement. The width of 0.2 mm is identified as the optimal, offering the widest impedance bandwidth of 2.97 – 7.53 GHz and lowest reflection coefficient of -23.20 dB among the investigated configurations.

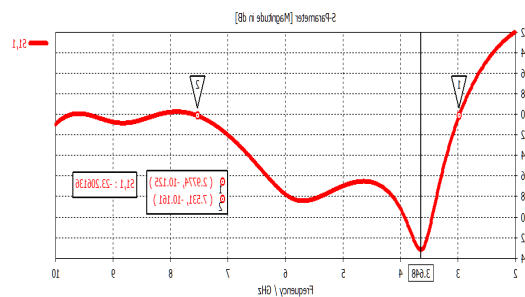


Figure 16: Return Loss Plot of the antenna with defected partial ground hexagonal ring of width 1.2 mm

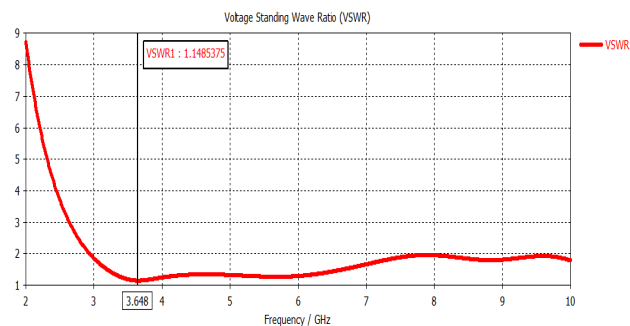


Figure 17: VSWR Plot of the antenna with defected partial ground hexagonal ring of width 1.2 mm

3.4 Gain and Directivity of the Antenna Using Notch 3 With Single Ring

The antenna gain measured in decibels (dBi), describe how antenna radiate electromagnetic energy in particular direction while the directivity measures the concentration of antenna radiation in specific direction. Figure 11 shows far field Gain that the main lobe magnitude was 2.92 dBi at the main direction was 159.0 deg with angular width of 84.8 deg with the side lobe level of the antenna also is -0.6 dBi. Similarly, the directivity at 6GHz with main lobe magnitude was 3.49 dBi at the direction of 159.0 deg with angular width of 84.8 deg. The gain value, being slightly lower than the directivity, reflects minor inherent losses within the antenna system; however, the difference is minimal, indicating acceptable efficiency.

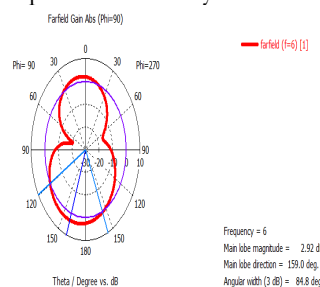


Figure 18: Polar plot of the gain of antenna at 6 GHz

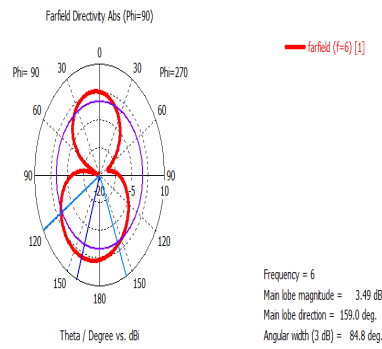


Figure 19: Polar plot of the directivity of antenna at 6 GHz

At 3.5 GHz, which falls within the WiMAX band, the antenna exhibits a main-lobe directivity of 2.95 dBi and a gain of 2.28 dBi. The low directivity and small gain difference indicate minimal losses and weak directional focus, resulting in near-omnidirectional coverage. Therefore, the antenna provides wide-area coverage with moderate range, making it well suited for applications that needs consistent signal availability across different directions rather than long-distance focused communication.

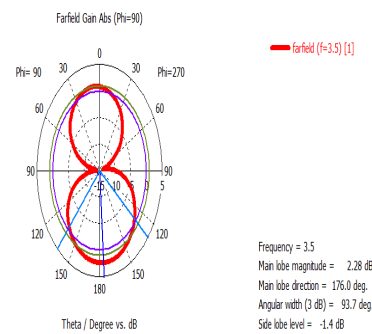


Figure 20: Polar plot of the gain of antenna at 3.5 GHz

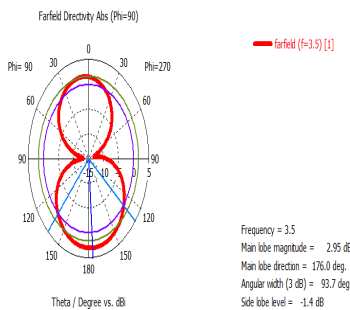


Figure 21: Polar plot of the directivity of antenna at 3,5 GHz

At 5.5 GHz, corresponding to the WLAN band, the antenna achieves a directivity of 3.4 dBi and a gain of 2.81 dBi. The improved directivity and gain at this higher frequency suggest better radiation focusing and efficiency, making it better for WLAN applications such as indoor wireless networking where enhanced throughput and reduced interference are important.

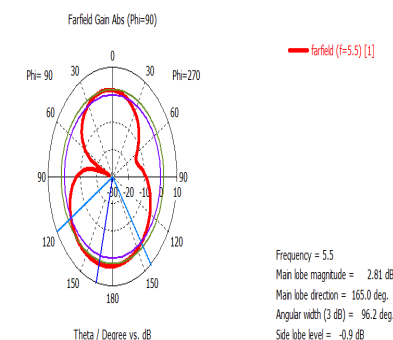


Figure 22: Polar plot of the gain of antenna at 5.5 GHz

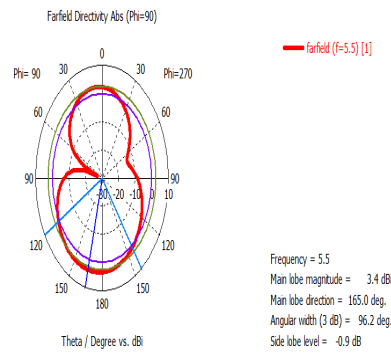


Figure 23: Polar plot of the directivity of antenna at 5.5 GHz

Overall, the antenna provides adequate gain, acceptable efficiency, and suitable radiation characteristics across both frequency bands, demonstrating its dual-band capability for WiMAX (3.5 GHz) and WLAN (5.5 GHz) applications.

3.8 Summary of Finding

The table shows the summary of the result. The conventional design has a narrow bandwidth of 160 MHz which shows a resonance frequency from 5.80 – 6.19 GHz and the voltage standing wave ratio between 1 and 2. Partial ground was also introduced which improves the resonance frequencies from 2.87 - 5.17 GHz. The wideband was achieved by clipping the bottom edge of the patch. While the antenna achieves the wideband of 4.56 GHz from 2.97 - 7.53 GHz. The modified antenna shows a lower reflection coefficient of -21.69 and -18.27 at 3.5 GHz and 5.5 GHz respectively. The VSWR was found to be 1.19 and 1.27. This indicates the modified antenna has better impedance matching with minimum signal losses. This antenna is well-suited for applications that require coverage of both WLAN and WiMAX frequency bands.

Table 2: Comparison between proposed design and the existing model

	Conventional Design	Design with Partial Ground	Modified Antenna	[5]
Resonance Frequency	5.80—6.19 GHz	2.87—5.17 GHz	2.97 - 7.53 GHz	5.05 - 6.15 GHz
Bandwidth	390 MHz	2370 MHz	4.56 GHz	1.1 GHz
Gain	-10.5 dBi	2.87 dBi	2.92 dBi	5.1 dBi
Directivity	-5.58 dBi	4.3 dBi	3.49 dBi	9 dBi
VSWR	1.09	1.13	1.14	NA
Return Loss	-27.31 dB	-23.79 dB	-23.20	-40

3.9 Comparison between Modified Antenna and Existing work.

The modified antenna operates over a much wider frequency range (2.97–7.53 GHz), covering multiple bands such as WiMAX, WLAN, and parts of C-band applications. In contrast, the existing antenna is limited to a narrow range mainly suitable for specific applications. The existing antenna has a higher gain (5.1 dBi), indicating better signal strength and longer communication range in its operating band. The modified antenna has a lower gain (2.93 dBi), suggesting more near-omnidirectional radiation and wider coverage area but shorter range.

Conclusion and Recommendations

This paper introduces the design of a modified wideband MP. The modification involves cutting the edge of the bottom of the patch and defecting the partial ground with single hexagonal slot. This modification results in the antenna exhibiting wideband characteristics, from 2.97 - 7.53 GHz, while maintaining a reflection coefficient of more than -10 dB. The paper assesses the antenna's return loss characteristics and radiation performance through CST simulations. This antenna is well-suited for applications requiring coverage of both WLAN and WiMAX.

As the proposed design achieved wideband, the future research should focus on improving gain and directivity. This can be achieved by using array configuration, 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. Furthermore, experimental validation and optimization can be done using

different substrate materials to enhance the antenna performance and adapt it for emerging 5G and internet of things applications.

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