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DESIGN OPTIMIZATION OF SLOTTED S-SHAPED MICROSTRIP ANTENNA FOR 5G APPLICATIONS FOR BANDWIDTH ENHANCEMENT

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ABSTRACT

The design and analysis of an extended slotted S-shaped microstrip patch antenna have been completed. The antenna exhibits wideband performance over the frequency range of 2.60–4.02 GHz and resonates at 3.18 GHz. In this design, three slots of different sizes are inserted to develop the proposed extended slotted S-shaped antenna. The bandwidth of the suggested antenna is 42.86% (1420 MHz) at a resonant frequency of -25.17 dB. Also, parametric analysis was done to look into how the antenna configuration affected return loss and resonant frequency. The gain variation of the suggested antenna is 3.43 dBi. An appropriate simulated antenna efficiency of 80.38% is also obtained. With a frequency coverage of 2.60 to 4.02 GHz, the antenna is appropriate for S-band (2-4 GHz) applications and conforms to WiMAX (3.4-3.69 GHz), IMT (3.4-3.6 GHz), and the n77 5G NR band (3.3-3.8 GHz), among other wireless communication standards. The designed antenna has been simulated on IE3D software. A coaxial-fed antenna has been used for proper impedance matching.

Keywords: Microstrip antenna, slotted antenna , WiMAX, n77, IE3D, bandwidth.

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1. INTRODUCTION

This has increased the demand for newer and innovative antenna designs with the rapid growth of wireless communication networks and escalation in the use of remote devices [1]. A significant advancement in antenna engineering, microstrip antennas provide unique characteristics that allow for applications ranging from 100 MHz to 100 GHz [2]. Due to their low-profile design and small form factor [3], microstrip patch antennas are commonly utilized in contemporary wireless communication systems. These features make them extremely appealing in the current wireless communication environment, where lightweight and compact components are of utmost importance. Connectivity options have significantly increased with the emergence of 5G cellular technology. Microstrip antennas are also becoming popular in the rapidly developing wireless communication field due to their cost-effective and efficient manufacturing considerations [4].

The microstrip patch antennas do have some drawbacks; they suffer from low gain, wide bandwidth, lowered efficiency, and reduced power handling capacity [5]. Patch antenna geometries of various types-such as rectangular and circular patch antennas-have been tried to overcome these handicaps. Such conventional configurations of patch antennas, like circular and rectangular patches, were modified into circular and rectangular ring patch antennas for improved bandwidth performance. Other studies have looked into octagonal patch antennas, hexagonal patch antennas, and octagonal star-shaped patch antennas with eight corners. Slot embedding in the ground plane or radiating element is used in other design methodologies, which incorporate geometric variations like triangular, U-shaped, and E-shaped slot configurations. These advancements have been made in an effort to improve important antenna properties, such as gain, bandwidth, and return loss, which will ultimately increase the microstrip patch antennas' operational range and performance.

One can attain multiple resonant frequencies and a wide impedance bandwidth in various ways by simply changing the shapes of the radiating patch and merging different types of slots and notches into it. A lot of research has been done and published in the form of papers, and these have been listed in Table-1. In [6], Yulindon et al. employed the PSO algorithm to create and fine-tune an E-shaped microstrip patch antenna for frequency applications to wideband (340-635 MHz). The antenna exhibited a gain of 3.246 dBi, an omnidirectional radiation pattern, and a bandwidth of 295 MHz was obtained. Deshmukh and Ray [7] came up with a 51 × 110 mm broadband antenna idea for GSM applications that included an L-shaped slot. Tutuncu [8] explains that a new particle swarm optimization method can substantially decrease the in-band radar cross-section of microstrip patch antennas by -26.4 dBi.It is superior in both size and efficiency compared to previous antenna designs. His colleagues, He *et al.* [9], proposed a compact U-slot-shaped antenna that can operate over a wide frequency range. Similarly, Kamakshi *et al.* [10] also proposed a new antenna design to enhance the bandwidth by using notch and slot methods. By means of an experimental π-shaped

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slot, the antenna reported by Sharma *et al*. [11] over the frequency range of 2.32 to 3.35 GHz achieved a bandwidth increase of 40.23%. Sun *et al*. [12] recommended the use of a shorting load to improve a small antenna's bandwidth performance. Zhang *et al*. [13] introduced a concept of a small, flexible end-fire antenna with a dual-mode, stub-loaded semicircular radiator.Tang *et al*. [14] developed a 3D-printed hemispherical antenna with optimized NFRP strips and the PSO algorithm, reaching a bandwidth of 17.97%, stable gain, and low-cost indoor wireless communication. A dual-input square patch L-shaped antenna was created by Nour *et al*. [15].

This report presents the design of an extended Slotted S-shaped compact antenna. The bandwidth of the rectangular MSA is improved by embedding three slots of different sizes in the radiating patch and exciting it through a 50-ohm coaxial probe feed line.Very few studies that have been considered from the literature on antenna design present bandwidths greater than 1300 MHz. Indeed, the proposed antenna shows 42.86% bandwidth (1420 MHz) ranging from 2.60 to 4.02 GHz in the S-band, thus suitable for the WiMAX/n77 5G NR band. The performance characteristics of the designed antenna were analyzed and validated using the IE3D simulator.

2. DESIGN OF THE PROPOSED ANTENNA GEOMETRY

The physical layout of the antenna to be designed is illustrated in Figure-1. The key topographies of the design include a small patch measuring 50 × 30 mm on a ground plane of 70 × 50 mm. A coaxial probe with 50 Ω impedance is placed at the border of the patch. The entire size of the antenna is given in Table-1.

Table-1. Dimension parameters of the design antenna.

Parameter	Value	Parameter	Value
Ground width (Wg)	70 mm	L_3	20 mm
Ground length (Lg)	50 mm	L_4	25 mm
substrate height (h)	1.6 mm	L_5	22.325 mm
Patch width (Wp)	50 mm	L_6	22.525 mm
Patch length (Lp)	30 mm	W_1	2.325 mm
Design frequency (fr)	3.18 GHz	W_2	14.25 mm
Dielectric constant (ε_r)	4.4	W_3	0.95 mm
$\mathbf{L_2}$	5 mm	W_6	1.75 mm
$\mathbf{L_1}$	24.075 mm	W_5	3 mm
Loss tangent tan $\boldsymbol{\delta}$	0.02	W_4	2 mm

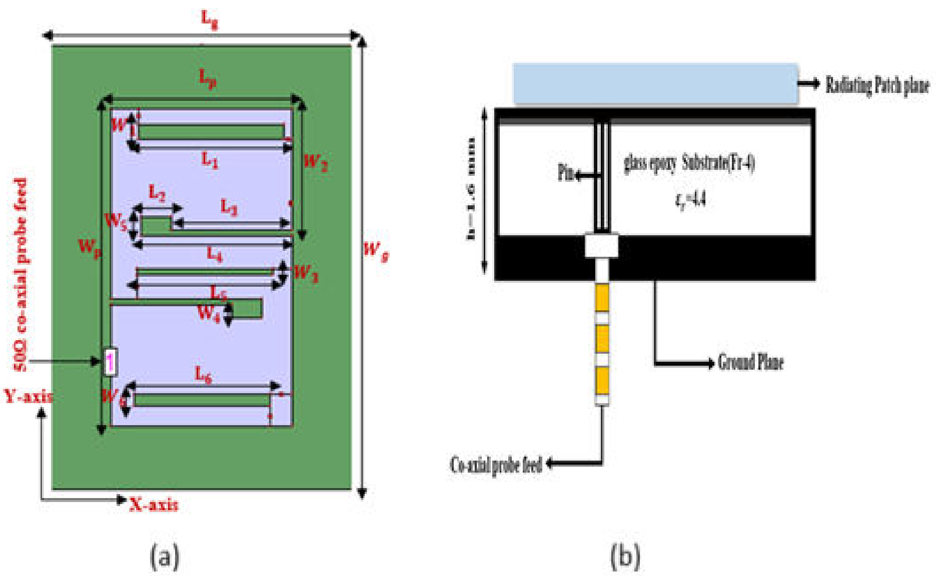

Figure-1. The proposed slotted S-shaped patch antenna geometry is shown with (a) representing the top view and (b) representing the side view.

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3. ANTENNA DESIGN PROCEDURE

The length and width of a Rectangular Microstrip patch antenna can be calculated using the parameters and equations listed below:

$$W_p = \frac{c}{2fr}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

Here, c signifies the speed of light in this context, while r = 4.4 denotes the dielectric constant of the substrate, which is made of glass epoxy material. Fr is the antenna design frequency, which is set to 2.25 GHz. Furthermore, W denotes the patch width, and $\varepsilon_{\text{reff}}$ denotes the effective dielectric constant.

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

At h=1.6 mm
The extension length is

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+.264\right)}{(\varepsilon_{reff}-.258)\left(\frac{W}{h}+0.8\right)} \quad (3)$$

From equation 3, the actual length of the patch is

$$L_p = \frac{c}{2f_r\sqrt{\varepsilon_{\text{reff}}}} - 2\Delta L \quad (4)$$

The length and the width of the ground plane are

$$L_g = 6h + L_p \quad (5)$$

$$W_g = 6h + W_p \quad (6)$$

To achieve a proposed S- S-shaped antenna structure, cut three slots of different sizes in the design antenna patch. The design frequency is set at 3.18 GHz. Careful calculation of all dimensions using the provided equations (1), (2), (3), (4), (5), and (6) is crucial for the successful implementation of this proposed microstrip patch antenna design.

4. PARAMETRIC ANALYSIS OF ANTENNA DESIGN

They used parameter variation to optimize the antenna geometry with parameter variation to make their overall performance better, and it led to a patch size of 30 × 50 mm, a notch size of 5 × 3 mm, and a slot dimension of 24.075 × 2.325 mm. The research work is conducted on the rectangular patch with the same 30 x 50 mm dimensions, whose length variations of 2 mm each are studied. Patch size variations include 32 × 50 mm, 34 × 50 mm, 36 × 50 mm, and 38 × 50 mm. Bandwidths of 42.99%, 43.50%, and 21.86% were achieved for the patch sizes of 32 × 50 mm, 34 × 50 mm, and 36 × 50 mm, respectively. These bandwidths correspond to return loss values of -34.65/-16.87, -24.72/-16.72, and -33.34 at frequencies of 3.04/3.89, 2.86/3.87, and 2.72, respectively. In addition, 11.23% and 12.18% bandwidths are achieved for the patch size of 38 × 50 mm, resulting in return loss of -21.16/-18.99 at a frequency of 2.62/3.87, respectively. Return loss plots for different dimensions of the patch and notch are demonstrated in Figures 2-4. The major bandwidth of 42.99% was realized with a patch of 32 × 50 mm for the variations of the patch length (Figure-2). So, the bandwidths for the widths 30 × 52 mm, 30 × 54 mm, 30 × 56 mm, and 30 × 58 mm were 44.06%, 43.55%, 41.79%, and 40.45%, respectively, whereas the corresponding return loss values were -29.7/-20.33, -32.85/-17.44, -34.22/-15.44, and -34.11/-14.82 at the resonant frequencies of 3.10/3.89, 3.06/3.89, 3.02/3.89, and 2.96/3.88 GHz. Based on Figure 3, the major bandwidth of 44.06% was recorded for a patch of 30 × 52 mm. The bandwidths resulting from 5 × 5 mm, 5 × 7 mm, 5 × 9 mm, and 5 × 11 mm notch sizes accounted for 43.27%, 44.70%, 44.70%, and 44.96%, respectively, while the return loss values were -26.58/-17.88, -28.58/-17.89, -29.66/-17.83, and -30.56/-17.43 at frequencies of 3.15/3.89, 3.13/3.89, 3.12/3.89, and 3.12/3.88 GHz, respectively. It was for a notch of 5 × 11 mm that the maximum bandwidth of 44.96% was recorded.

Finally, a rectangular horizontal slot of 24.075 x 2.325 mm is considered. Four different slot lengths are taken by varying 2.5 mm: 24.075 × 4.825 mm, 24.075 × 7.325 mm, 24.075 × 9.825 mm, and 24.075 × 12.325 mm. The bandwidths for these slot sizes are 43.31%, 43.53%, 43.67%, and 43.81% for return losses of -26.74/-17.10, -27.68/-17.03, -28.33/-16.81, and -28.68/-16.76 at frequencies of 3.15/3.89, 3.15/3.91, 3.15/3.91, and 3.15/3.93, respectively. The return loss response was examined for various slot widths, as seen in Figure-5. With a slot size of 24.075 × 12.325 mm, the antenna's maximum bandwidth was 44.81%. The suggested design's optimal measurements are 30 × 50 mm for the patch, 5 × 3 mm for the notch, and 24.075 × 2.325 mm for the slot.

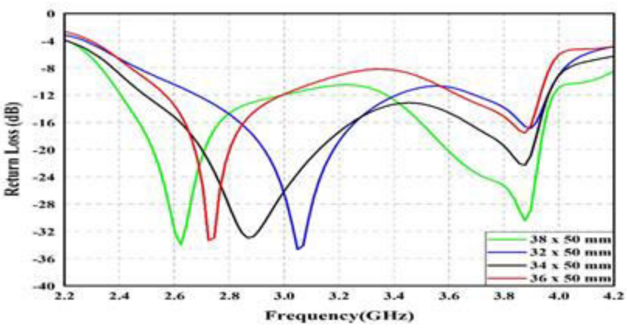

Figure-2. Patch size variation in mm (Length) at sizes 32 × 50, 34 × 50, 36 × 50, and 38 × 50.

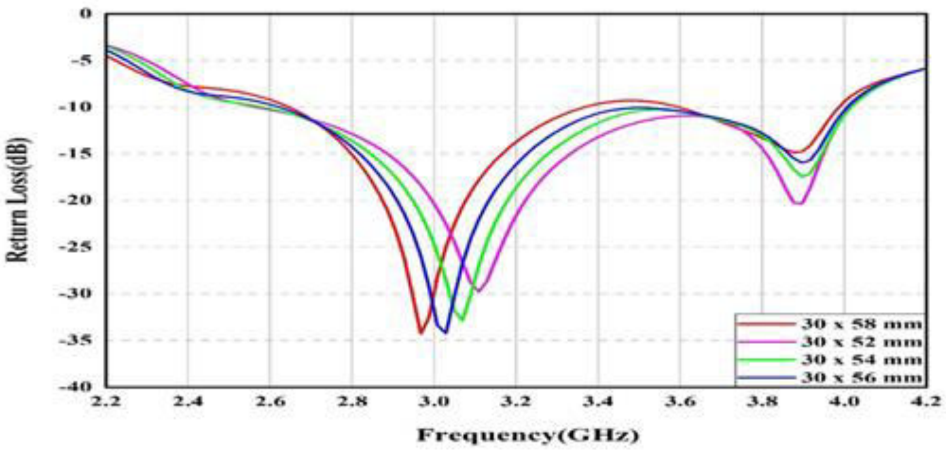

Figure-3. Patch size variation in mm (Width) at sizes 30 × 52, 30 × 54, 30 × 56 and 30 × 58.

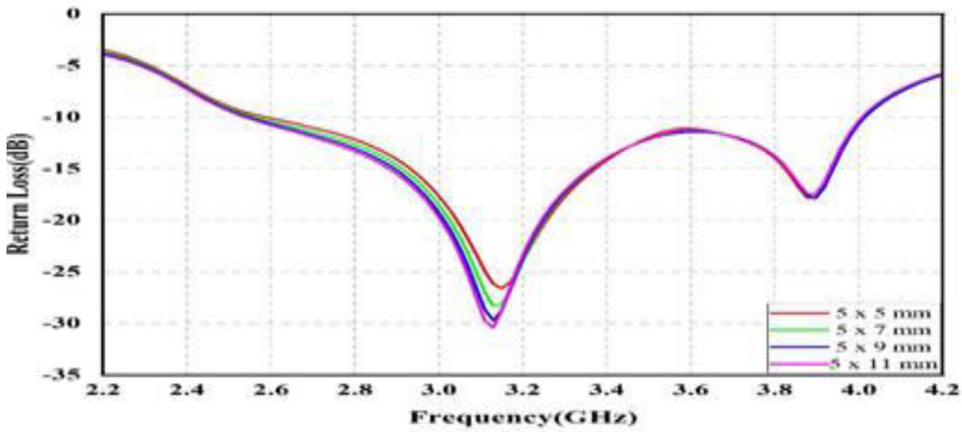

Figure-4. Notch size variation in mm (Width) at sizes of 5 x 5, 5 x 7, 5 x 9, and 5 x 11.

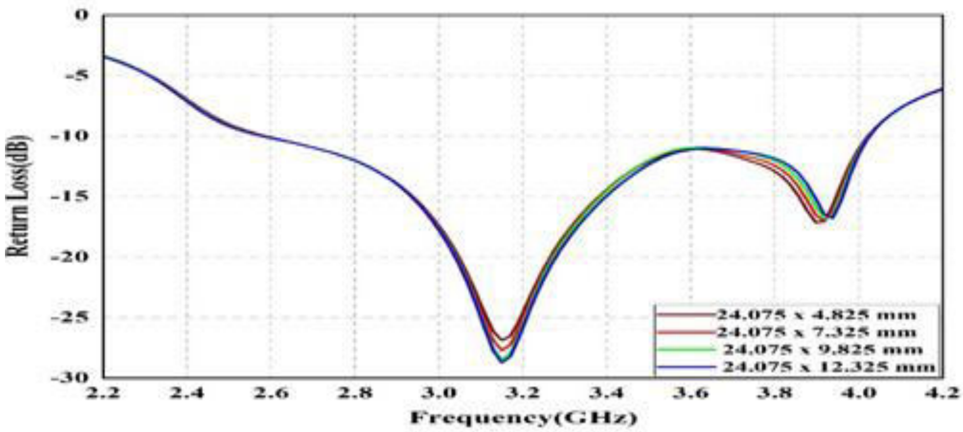

Figure-5. Slot size variation in mm (Width) at sizes 24.075 × 4.825,24.075 × 7.325, 24.075 × 9.825 and 24.075 × 12.325.

5. RESULTS AND DISCUSSIONS

The analysis of the projected antenna is accomplished with the IE3D software tool at its resonant frequency of 3.18 GHz. The important parameter value has been calculated, and a graph has been plotted for a frequency range from 1 GHz to 7 GHz. In Figure-7, return loss against frequency is plotted; this curve crosses -10 dB at a lower frequency range of 2.60 to 4.02 GHz. The bandwidth is 42.86% (1420 MHz) by simulation, and the return loss is -25.17 dB at 3.18 GHz of resonance. The

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experimental value of bandwidth is 26.83% (750 MHz) in the frequency range of 2.42 - 3.17 GHz, and the experimental value of return loss is -27.58 dB at 2.68 GHz resonance. The hardware of the projected antenna is fabricated from FR-4 glass epoxy PCB, and its thickness is 1.6 mm. The front view and back view of the antenna are shown in Figures 6(a) and 6(b), respectively. Figure-7 also presents a comparison plot of simulated and measured values of return loss. Figure-8 presents the measurement setup done for an experiment to plot the graph between return loss vs. frequency. The simulated and experimental values of important parameters are shown in Table-2. A small difference is observed in the parameter values of the simulated and measured due to some fabrication fault in the soldering of the connector of the feed point and the fabrication of the hardware design during etching. As plotted in Figure-9, directivity vs. frequency at the frequency of 3.18 GHz. The gain plot is shown in figure 10. The radiation pattern at the frequencies 3.12 GHz and 3.84 GHz is demonstrated in Figures 11(a) and 11(b), respectively. Proposed antenna gain is 3.43 dB at 3.18 GHz resonance, while it is 4.60 dB at peak frequency 4.02 GHz. The directivity is 4.38 dB, and the efficiency is 80.38 %.

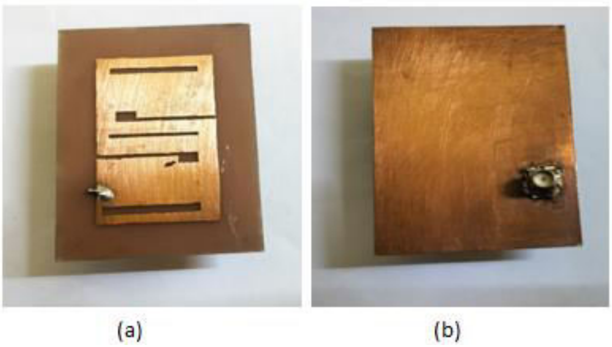

Figure-6. Physical view of the designed antenna design (a) front (b) Back.

Table-2. Comparison of parameter values using simulated and measured.

Antenna Parameters	Simulated	Measured
Resonant Frequency (GHz)	3.18	2.68
Return Loss(dB)	-25.17	-27.58
Bandwidth (%)	42.86	26.83
Band Range (GHz)	2.60 - 4.02	2.42-3.17

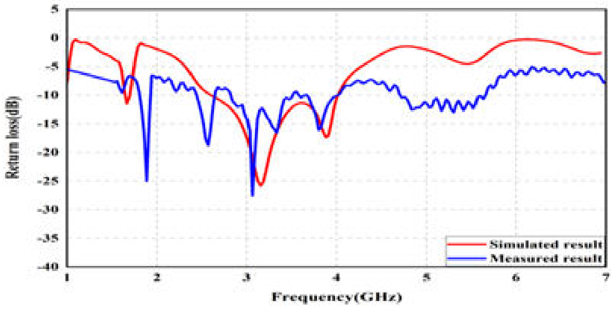

Figure-7. Comparative graph of simulated vs. experimental.

Figure-8. Experimental graph return loss vs. frequency using a spectrum analyser.

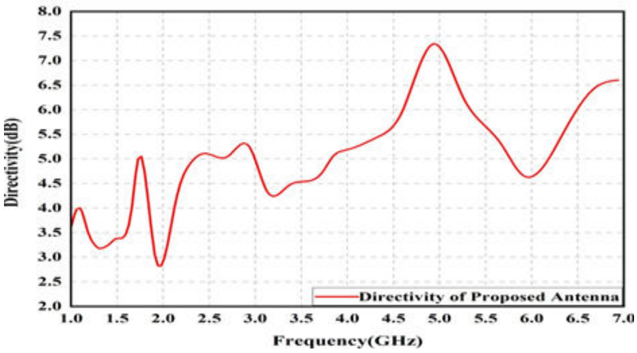

Figure-9. Directivity vs. Frequency graph.

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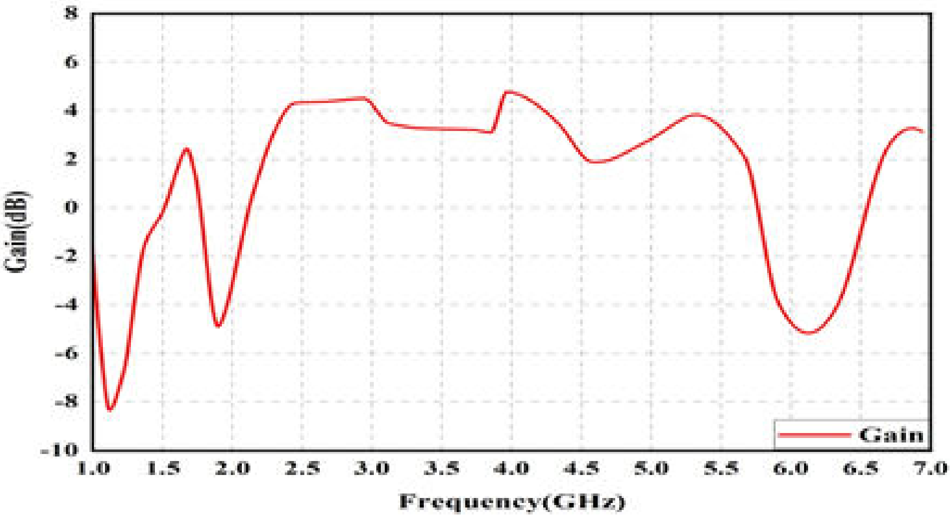

Figure-10. Gain vs. Frequency graph.

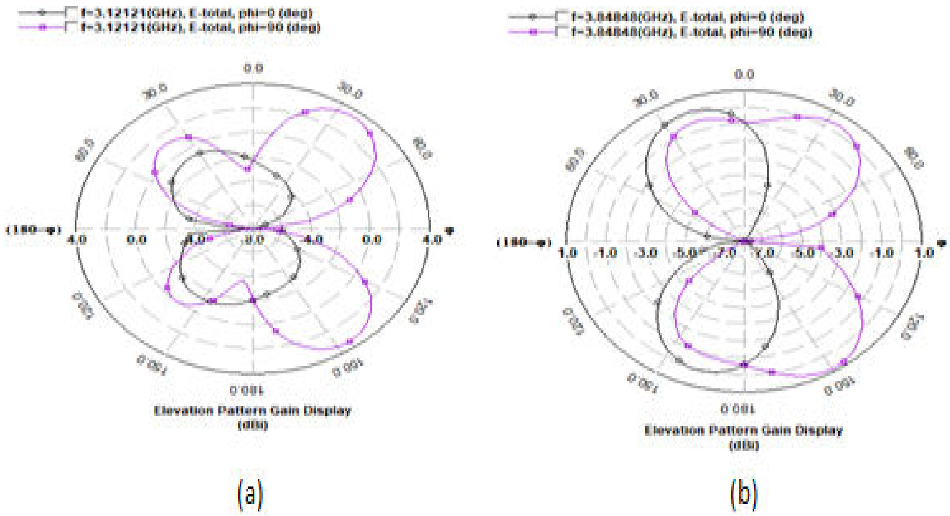

Figure-11. Radiation pattern graph (a) 2.23 GHz (b) 6.64 GHz.

6. CONCLUSIONS

The novel slotted S-shaped microstrip antenna has been designed at a resonant frequency of 3.18 GHz.The S-shaped microstrip antenna is well simulated and analysed with important parameters. The designed antenna is also fabricated, and the physical antenna is analyzed using a network analyzer. The bandwidth is 42.86% (1420 MHz) by simulation, and the return loss is -25.17 dB at 3.18 GHz of resonance. The experimental value of bandwidth is 26.83% (750 MHz), and the experimental value of return loss is -27.58 dB at 2.68 GHz resonance. Proposed antenna gain is 3.43 dB at 3.18 GHz resonance, while it is 4.60 dB at peak frequency 4.02 GHz. The directivity is 4.38 dB, and the efficiency is 80.38 %. The above date exhibits that the projected antenna can be applicable in S band, Wi-MAX, IMT, n77, and 5G.

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