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Original Article

A G-Shape Slot Rectangular Microstrip Patch Antenna for Microwave Applications

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Abstract - *The antenna is the main component of wireless communication, which these systems use to transmit and receive electromagnetic waves. Rapid advancements in wireless communications call for smaller, more innovative devices with a broader range of supported applications and higher frequency bands. The best alternative to conventional antennas is microstrip patch antennas (MPA). In this research, a rectangular MPA with a G-shaped slot is presented. The suggested antenna covers three bands of 7.51, 8.01, and 10.68 GHz, and each band has a perfect return loss of roughly -37.6, -19.5, and -54.1 dB. The gain of the provided antenna is 6.257 dB, and the efficiency is about 97.35%. CST simulation software was used for the antenna structure's design and modelling, with positive results.*

Keywords - *Microstrip antenna, Microstrip patch antenna, Rectangular patch antenna, G-slot, Microwave applications.*

1. Introduction

Due to its critical role in boosting the effectiveness of contemporary communication systems applications, today, the antenna is regarded as one of the fundamental components of wireless communication systems. Therefore, employing a high-frequency and ideal data transfer rate is necessary to construct a practical antenna. Additionally, to reduce the overall size of the communication equipment, the antenna should be designed as tiny as feasible. A planar antenna known as MPA has gained much attention in recent years. It comprises a metallic patch printed on a grounded surface or hung above a ground plane. The MPA offers several benefits, including multiple existing designs, simplicity in production, small size, lightweight, low cost, and a uniform shape that satisfies the needs of wireless communication systems [1][2]. As a result, the demand for MPA has risen quickly. At the same time, it has become crucial to overcome the operational problems of microstrip antennas, like their limited bandwidth, low gain, and decreased efficiency, to improve the MPA's efficacy [3].

According to most earlier studies on this subject, the MPA's shape and substrate characteristics have a considerable role in determining how well the antenna performs and how effectively it is used, depending on the application [4][5]. Numerous applications called for a single band with a large data transfer bandwidth while minimizing the size as feasible. The C-shaped patch antennas, for instance, have been suggested in earlier research to achieve a size reduction of around 67% [6] and 37% [7] compared to a conventional microstrip patch. The MPA with an H-shape slot, another form of antenna, is precisely researched with a broad bandwidth of nearly 19% [8]. In addition, a rectangular MPA with a U slot cut out at the corner is recommended for bandwidth augmentation [9], which achieves a bandwidth of around 80.41%. It is suggested [10] to use a broadband antenna with an E-shaped patch to get a 30.3% wide bandwidth.

Incorporating different communication gauges at one antenna increased the demand for a mobile wireless network. As a result, a multiband antenna that uses many frequency bands became highly desirable. This handy feature helps to avoid employing numerous antennas at once. As a result, several effective dual and multiple-band planar antenna designs have been briefly examined and developed to improve the antenna's usefulness for wireless communication applications.

In [11], a single-band MPA with a 3.5 GHz operating frequency was suggested, with an efficiency was 89.56%. In [12], a single-band 28 GHz MPA for Mobile 5G communications was introduced. An innovative technique for boosting efficiency, lowering VSWR, and broadening the bandwidth of microstrip patch antennas was proposed in [13]. The 29.416 GHz 5G band was recommended for using the antenna. According to the simulation's data, 900 MHz is the bandwidth, -44.78 dB is the return loss, and 1.0115 is the VSWR. For use in V-band communication systems, two wideband microstrip rectangular patch antennas with 45 GHz and 60 GHz resonance frequencies have been constructed and modelled in [14]. The 45 GHz antenna has a 1.03 VSWR, a 5.5 GHz bandwidth, and a gain of 6.73 dB.

In contrast, the bandwidth of 11.57 GHz, 6.92 dB of gain, and 1.05 VSWR are present in the 60 GHz design. The findings demonstrate both concepts' viability and suitability for application in the V band or the forthcoming 5G communication systems. The [15] displayed a microstrip antenna design with a hexagon-shaped radiating patch for Ultra-Wide Band (UWB) applications. The modelling results of the proposed antenna indicate a gain of about 5.32 dB and efficiency is 90.88%. The recommended antenna construction delivers a return loss of less than -10 dB over frequencies of 3.1 - 10.6 GHz.

A C-shaped slot dual-band MPA with 12.05% and 19.82% bandwidth was examined in [16]. A dual-band G-patch antenna with bands of (3 and 3.8) GHz was suggested in [17, 18]. The design of a modified microstrip UWB antenna with triple band characteristics, covering the frequencies of (3.3 - 3.6 GHz), (5.1 - 5.8 GHz), and (7.25 - 8.4 GHz), was designed in [19]. A small reverse G-shape UWB antenna with a notch has been presented in [20] and achieves a (3.2 - 10.9) GHz bandwidth. 510MHz, 1.3 GHz, and 1.21GHz are the bandwidths of a triple-band MPA suggested in [21, 22] that has a strip connected at the right side of an O-shaped patch and a modified ground plane using the inverted L slot and unequal two slits.

A novel small MPA with a radiating double-slotted patch and the optimal voltage standing wave ratio (VSWR) was Simulated and developed in [23]. This proposed antenna operates in frequencies of 2.41 and 3.27GHz, making it optimal for RADAR, satellite, ISM, and Wi-Fi band applications. The band of ISM, which spans the 2.4 to 2.483GHz range, is also a part of the S-band. This band has applications in industry, science, and medicine.

A small Triple Band MPA was described in the prior study [24]. Two L-shaped slots were added to the antenna's design for size reduction, multiband functionality, and defective ground structure (DGS) for bandwidth increase, and 4.4, 6.2, and 8.5 GHz are the resonance frequencies of the antenna. In [25, 26], reactive loads were used to construct a rectangular tri-band patch antenna that produced 5.8%, 3.7%, and 1.57% impedance-matching bandwidth. In [27], a tri-band modified rectangular microstrip patch antenna with frequencies of 6.19, 7.63, and 10 GHz was introduced. To accomplish bandwidth (208.5, 887.7, 751.8, and 460.6) MHz, a Quad-Band U-shaped slotted microstrip antenna was built [28].

Regarding the current work, a small and easy simple antenna was presented. A tri-band rectangular patch with a G-shaped slot and coaxial probe feed are proposed.

Table 1. The values of the parameters of the suggested antenna

Parameters	Values (mm)
Width for Substrate (W_s)	15
Length for Substrate (L_s)	13
Height for substrate (h)	1.6
Width for Patch (W_p)	7
Length for Patch (L_p)	6
Width for slot (W_{slot})	0.25
L_1	5
L_2	6.5
L_x	4
L_v	3.25
E_r	4.3

The patch was designed on a dielectric material with the etching of a G-shaped slot. The antenna provides a stable gain and bandwidth polarisation with acceptable cross-polarization levels. A G-slot was considered significant to minimize the antenna size and get satisfactory reflection coefficient results. The simulation studies were performed using the CST software. Following is a summary of our work's key contributions:

1. We study the role of antenna size on antenna performance by designing two antennas with the same slot type but in different sizes.
2. We perform a robustness analysis to evaluate the performance of the G shape slot on the antenna performance.
3. We emphasize antenna size's impact on bandwidth through our simulation results.

The remainder of this research is structured as follows: Section 2 elucidated the antenna structure and theoretical considerations. The simulation results are explained in Section 3. Finally, the overall study conclusions, recommendations, and suggestions for future works are clarified in the last Section 4.

2. Design of Antenna

The proposed structure of the wideband MPA is displayed in Figure 1, which consists of a substrate, ground plane, and radiator patch with a slot-shaped G letter, as shown in Figure 1b. On a substrate of FR-4, the antenna was designed with a relative permittivity of 4.3 and a total size of 15 x 16 x 1.6 mm^3. The bottom layer is the ground plane with the same scale as the substrate, while the upper layer is the patch with $0.69\lambda \times 0.59\lambda$ (where λ is one wavelength in the air at 2.94 GHz). The patch has an engraved G-shaped slot fed by a coaxial cable. Table 1 displays the exact antenna dimensions. The antenna was fed input EM waves from the exporter using a coaxial wire with a 50 ohm impedance.

Table 2. Comparison of the suggested antenna with references antennas

Ref	Dimensions of a patch (mm^2)	Thickness of substrate	Slot shape	Feeding type	Resonant frequency (GHz)	Return loss (dB)	Bandwidth	Gain (dB)	Efficiency
Ref 6	24.3 X 28.3	1.5	Inverted C	Microstrip line	2.53	-19.104	-	5.67	-
Ref 7	30 X 30	1.6	H	Coaxial cable	2.42	-	19%	-	-
Ref 9	50 X 70	1.5	E	Coaxial cable	1.9 2.4	-	30.3%	-	-
Ref 10	48 X 96	-	C	Coaxial cable	1.25 2	-16.25 -23.75	12.05% 19.82%	5.509	89%
Ref 14	36.35 X 49.41	1.588	Reactive loads	microstrip line	2.4 3.5 5.7	-	5.8% 3.7% 1.57%	-	-
Current Study	7 X 6	1.6	G	Coaxial cable	7.51 8.01 10.68	-37.6 -19.5 -54.1	15.47%	6.26	97.35%

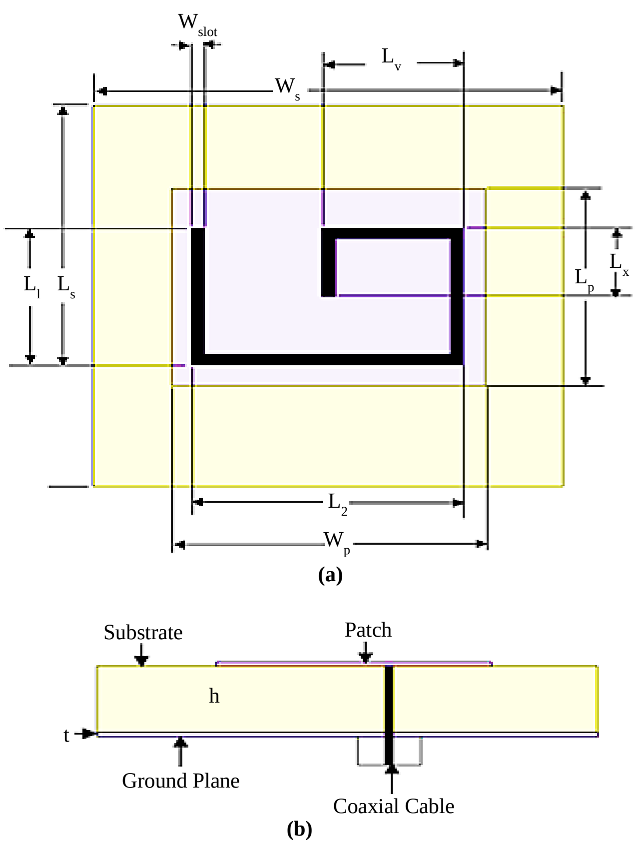


Fig. 1 The structure of the presented antennas: (a) Upper view, (b) Side view

The coaxial cable's outer conductor is connected to the metallic patch by the ground plane, and the inner probe of the coaxial cable makes an instant connection to it. From the feeding stage, currents go to the higher and lower rims. Utilizing those currents' travel lengths, the values are computed.

3. Results and Discussions

In this research, we offer a tiny antenna for microwave applications. The performance of an antenna, including efficiency, gain, and radiation pattern, is influenced by the size of a ground plane. For optimal performance, the ground plane must extend over the boundaries of the patch by a distance at least 2-3 times the substrate thickness (h). While the frequency is less impacted by the modest size of the ground plane, the front-to-back ratio decreases due to its size. The giant ground plane slightly affects the gain since it will grow. The frequency is regulated by the radiator length (patch length), which is about λ/2 from a rectangular patch. The suggested antenna was initially tuned to obtain the desired feature.

The suggested antenna design and simulation studies were conducted using commercial electromagnetic simulation CST software. The improved tri-band antenna's simulated S-Parameters (S11) curves are presented in Figure 2 with and without a G slot. The return loss values are explained on the Y-axis; the range of operating frequencies is illustrated on the X-axis.

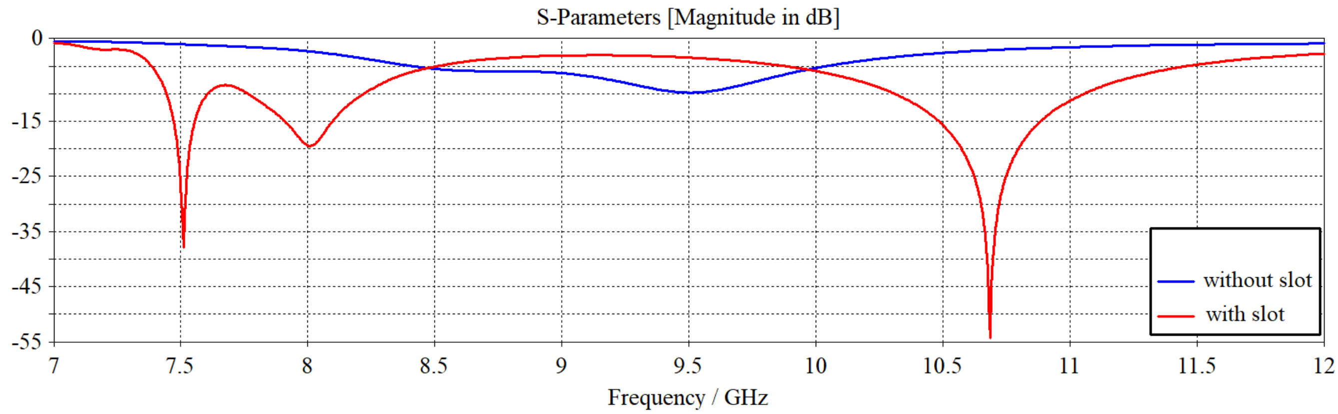


Fig. 2 Shows the proposed tri-band antenna's simulated return loss curve with and without a G slot

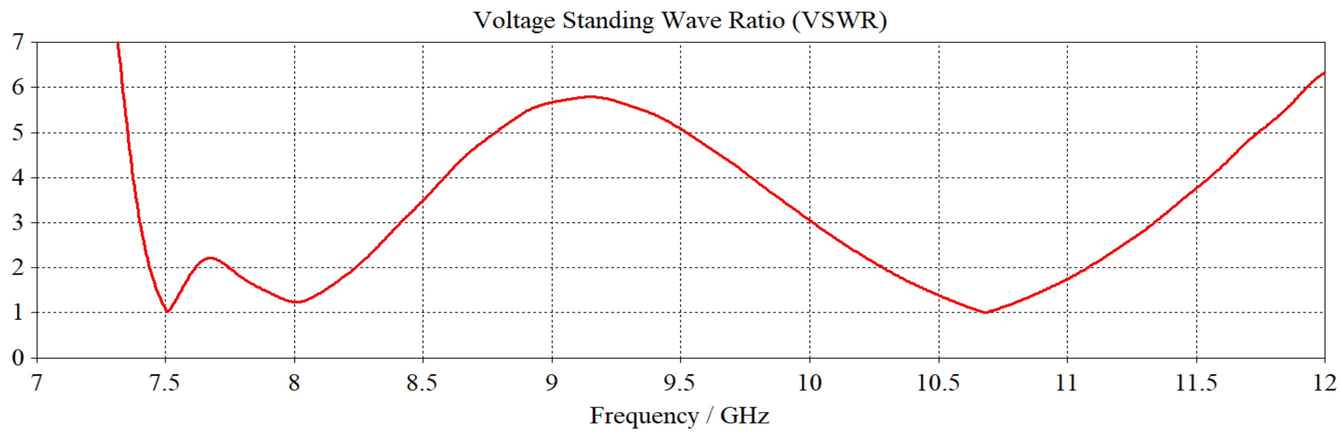


Fig. 3 Shows the tri-band antenna's VSWR

The plot shows that the G slot matches the antenna's impedance because the current stream changes when the slot cuts out in a patch. The current flow in the antenna with the slot is more than without. Also, the Figure presents triple bands with adequate bandwidth at specified frequencies. The resonance frequencies of the antenna were 7.51, 8.01, and 10.68 GHz, and it showed reflection coefficients of -37.6, -19.5, and -54.1 dB, respectively.

The three operational bands' simulated bandwidths with 10dB down impedance were determined to be 160 MHz (7.44–7.6 GHz), 440 MHz (7.76–8.2 GHz), and 270 MHz (10.55–10.82 GHz). The VSWR describes the impedance matching of the transmission line. Figure 3 displays VSWR < 2 at resonance frequencies. The VSWR is 1.03 at frequency 7.51 GHz, 1.24 at frequency 8.01 GHz, and 1.004 at frequency 10.68 GHz.

3.1. Effects of the Length (L_x)

Figure 4 depicts the response of the planned antenna for the G slot at various lengths (L_x). When the operating frequency range is depicted on the X-axis, the return loss is displayed on the Y-axis. According to the Figure, return loss dropped across the board and moved in the upper operating frequencies toward the upper frequencies when the value of (L_x) rose from 4 to 4.75mm. The larger size of (L_x) will improve capacitance and decrease inductance; however, the lower frequencies went toward Lower values. Consequently, the degree of return loss will diminish.

3.2. Effect of the Length (L_v)

The response of the suggested antenna at various length values (L_v) is shown in Figure 5. It will cause the lower and higher resonance frequencies to move toward the Lower side and decrease for the same reasons on upper quantities of (L_v) from 3 mm to 3.75 mm. When the quantity of (L_v) is 3.25mm in this Figure, we receive the best return losses.

3.3. Effect of the Width (W_{slot})

Figure 6 illustrates how slot width (W_{slot}) affects return loss. When the operating frequency range is depicted on X-axis, while Y-axis displays the return loss values. The Figure demonstrates that the decrease in width will result in favourable return loss characteristics. Therefore, because the slot's width impacts the antenna's current flow, it significantly impacts its response. The Figure shows when (increased from 0.25mm to 1mm. The reflection coefficients will shift to upper frequencies at both Upper and lower frequency values. The distributions of the current surface at the frequencies for the suggested antenna have been examined for comprehending the band's electromagnetic radiation pattern better, as shown in Figure 7. The slit (L_v) of the G slot structure in Figure 7 displayed a broad density of surface current when the suggested antenna operated at a resonance frequency of 7.51GHz, as illustrated in Figure 7a. The surface current density observed with the G slot at the second and third frequencies of 8.01 and 10.68 GHz is depicted in Figures 7b and 7c.

Figure 8 depicts the planned antenna's simulated E-plane and H-plane radiation patterns. The directional radiation patterns in E and H planes are shown in Figure 8a. The H-plane in Figure 8b is roughly omnidirectional, but E-plane is directed. In Figure 8c, the H plane is directional, but the E plane is roughly omnidirectional. Table 2 compares our antenna and a few antennas from the literature. Our antenna performed well when compared to these antennas.

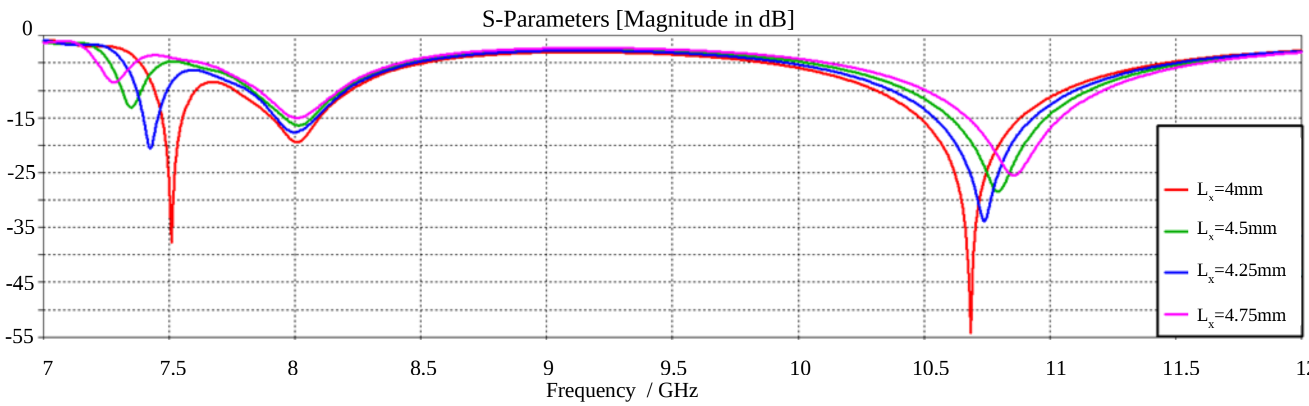


Fig. 4 Displays the return losses for different lengths of L_x

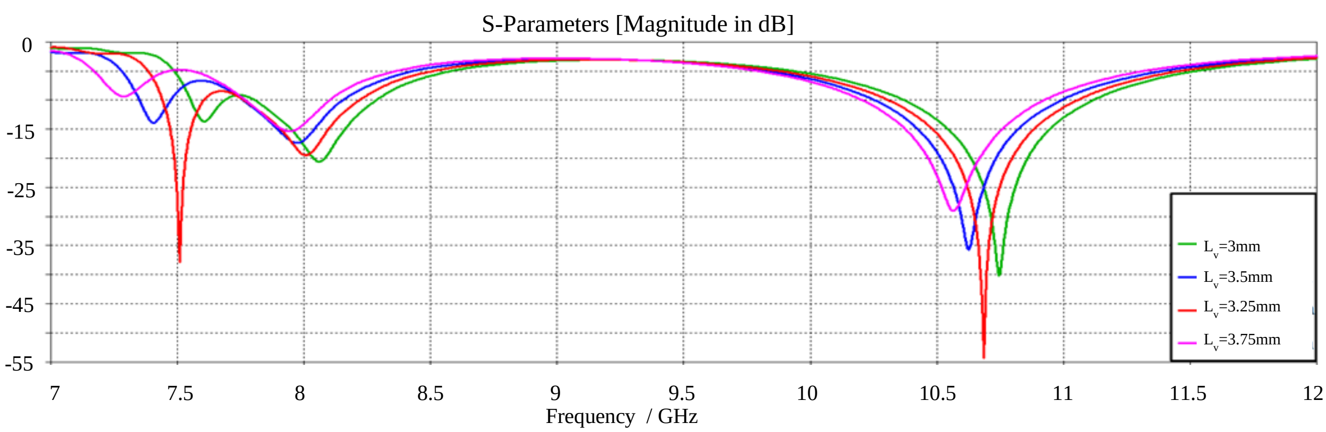


Fig. 5 Shows the return losses for different lengths of L_v

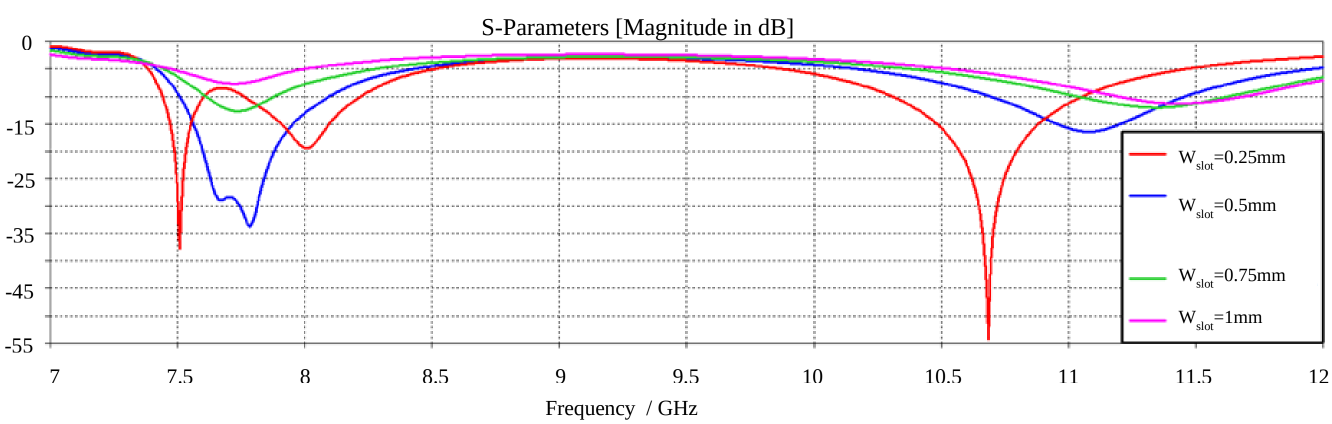
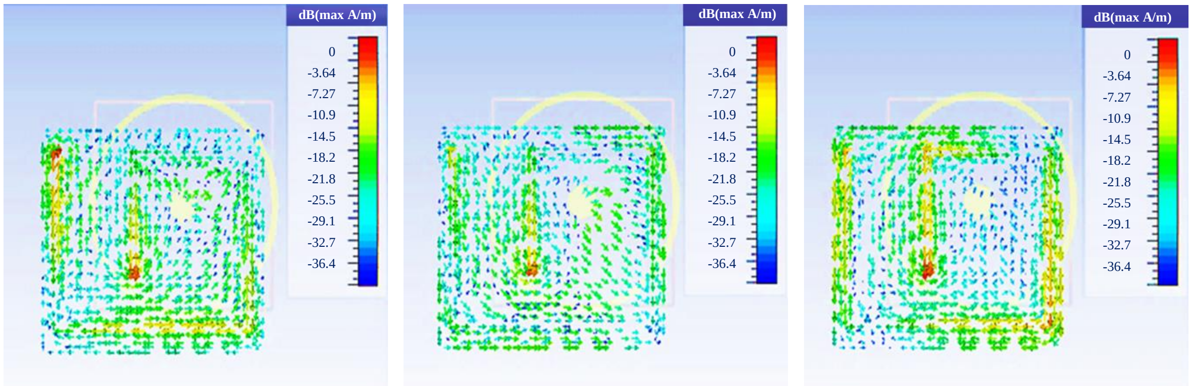
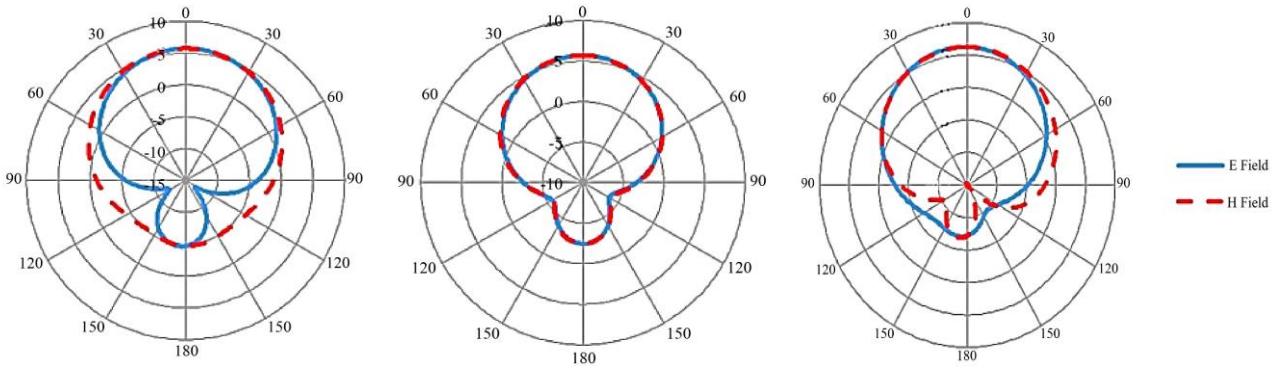


Fig. 6 Shows the return losses for different values of the width of W_{slot}



(a) **(b)** **(c)**

Fig. 7 Shows the proposed antenna's surface current patterns over three bands (a) 7.51 GHz, (b) 8.01 GHz, and (c) 10.68 GHz



(a) **(b)** **(c)**

Fig. 8 Shows the tri-band proposed antenna's simulated E and H radiation patterns at (a) 7.51 GHz, (b) 8.01 GHz, and (c) 10.68 GHz

4. Conclusion

The present work proposed a tri-band rectangular patch with a G-shaped slot. The antenna's performance improved, with a bandwidth of about 15.47% and an efficiency of 97.35%. The proposed antenna is smaller and can be utilized for microwave applications. The antenna provided a stable gain and bandwidth polarisation with acceptable cross-polarization levels. The simulation results found that the suggested antenna frequencies and bandwidth depend on the G-slot parameters and substrate thickness. We can fabricate these antennas in the future.

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