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Improvement of Bandwidth and Gain of a Rectangular Patch Antenna for UWB Applications

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ABSTRACT: The crucial drawbacks of a microstrip patch antenna are its limited bandwidth and low gain. A rectangular patch microstrip antenna for UWB applications is proposed in this article, which has been designed to overcome these limitations by embedding right-angle triangular-rectangular slots into the patch and adding a single rectangular slot into the partial ground plane. The antenna is designed on FR-4 substrate with a total size of $30 \times 20 \times 0.8$ mm^3, a dielectric constant of 4.4, a thickness of 0.8mm, and a loss tangent of 0.02. The simulation results show that the rectangular patch microstrip antenna (RPMA) with slots achieves a wide bandwidth of 19.7 GHz (3.15 - 22.85 GHz) and a maximum gain of 8.06 dB, which is 16.02 GHz and 3dB greater than the rectangular patch microstrip antenna (RPMA) without slots.

KEYWORDS: Rectangular slot, Right-angle triangular slots, UWB, FR-4 substrate.

I. INTRODUCTION

A microstrip patch antenna (MPA) has significant disadvantages such as narrow bandwidth and low gain, even though it is smaller in size and easy to manufacture [1]. Several studies have been performed in which researchers have demonstrated various strategies and methodologies in order to address the impediments that have also been discussed in the literature review. The greater bandwidth of an antenna is a major challenge in the development of communication, which may radiate across a wide range of frequencies. On the contrary, with a higher gain, an antenna can show better performance. As a result, it is critical to apply specific strategies to overcome the basic problems of the patch antenna. An MPA consists of a substrate with a relative permittivity of ε_r and a ground plane. A patch of any shape (rectangular, round, square, elliptical, dipole, and triangular) and size is designed on the substrate [2]. The antennas, manufactured on PCB using microstrip techniques, often work at microwave frequencies. The most frequently used MPAs are rectangular and circular because they give different frequency operations, circular or linear polarization, the versatility of the feedline, and adaptability to array configuration [3]. A feeding line is needed to excite the antenna. Researchers are using different feeding line techniques, like a coaxial probe, microstrip line, aperture coupling, and proximity coupling [4].

We have used microstrip line feeding for our study, in which the microstrip patch is directly aligned with the conducting microstrip feed line (Fig.1). The two most common ways to improve the bandwidth of a microstrip patch antenna are to increase the substrate height or lower the substrate dielectric constant [5]. However, raising the substrate height makes the antenna no longer small, and decreasing the dielectric constant further reduces the resonance, which may cause problems at higher frequencies. In order to improve the gain, a low-loss substrate should be used [6].

In this paper, the antenna is designed in two stages; the first stage is a rectangular patch microstrip antenna (RPMA) without slots, and the second stage is a RPMA with slots. The goals are to improve the gain and bandwidth performance of the antenna.

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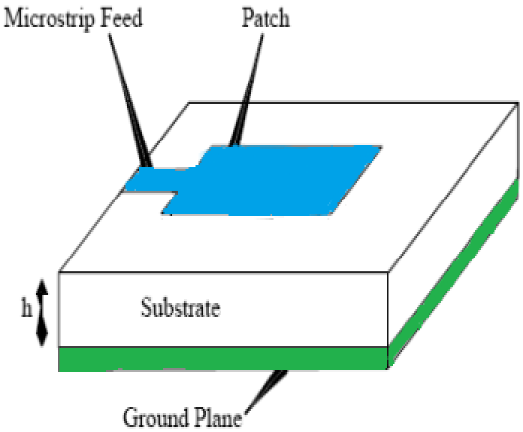

FIGURE 1. Microstrip patch antenna with Microstrip line feeding.

II. LITERATURE REVIEW

A miniaturized size ultra-wideband microstrip antenna based on a metamaterial array was designed for UWB applications by A.F. Darweesh and G.O. Yetkin [7] using computer simulation technology (CST) software. The antenna is 36 × 38 × 1.58 mm^3 in size and has a partial ground printed on the FR4 dielectric substrate. The metamaterial array is made up of two triple split-ring resonators that are placed above the antenna structure. The results noted that an improved bandwidth of 2.6 GHz – 20 GHz with a gain of 5.6 dB was achieved. J. Vijayalakshmi and G. Murugesan [8] presented a miniaturized high-gain (MHG) ultra-wideband (UWB) unidirectional monopole antenna with defected ground structure (DGS) for ultra-wideband applications. The MHG antenna is printed on FR4 substrate material and has a total size of 26.6 mm × 29.3 mm × 1.6 mm. It works in the UWB frequency band and has a bandwidth of 3.1 GHz to 10.6 GHz. This antenna shows a peak gain of 7.20 dB with an efficiency of 95% and a bandwidth of 3.2 – 10.6 GHz.

S. Patel and C. Argyropoulos [9] improved bandwidth and gain in a compact microstrip antenna by using multiple corrugated split-ring resonators (SRR) metamaterials. Square teeth have been added to the outer edges of SRR rings in the corrugated designs. The effectiveness of a microstrip antenna loaded with eight different SRR loads is analyzed. Through their investigation, they were capable of achieving a higher bandwidth of 420 MHz with a gain of 7 dB. M. Samsuzzaman, M.T. Islam, and J.S. Mandeep investigated the microstrip patch antenna with a single feed, new shape, compact size, and high gain [10]. The antenna has an overall dimension of 9.5 mm × 7.96 mm × 1.905 mm and is printed on Rogers RT/duroid 6010 substrate material. The triple equalitarian triangular slot is used to decrease the size of the antenna and enhancing the bandwidth. The antenna achieves a gain of 6 dB and operating bandwidth of 15.27 – 15.72 GHz.

Abbas et al. [11] developed a double-sided printed antenna with a parasitic patch for ultra-wideband (UWB) applications. The antenna is printed on FR4 epoxy substrate material and has an overall size of 30 × 24.8 × 1.6 mm^3. It has an asymmetric feed line with an impedance of 50 Ω. The antenna shows a 7 dB gain and an 11.51 GHz extended bandwidth ranging from 1.69 to 13.2 GHz. S. Baudha and M.V. Yadav [12] proposed a compact UWB planar antenna with a corrugated ladder ground plane for a variety of applications. The antenna is 15 × 20 × 1.5 mm^3 in size and is made on a low-cost, relatively cheap FR-4 substrate with relative permittivity of 4.3, a permeability of 1, and a loss tangent of 0.025. The impedance bandwidth and peak gain of the antenna are 130.4% (2.4 – 11.4 GHz) and 3.5 dB, respectively.

S. Baudha and M.V. Yadav investigated a novel design for UWB applications of a planar antenna with a modified patch and a defective ground plane [13]. The antenna has an optimal dimension of 20 × 25 × 1.5 mm^3 and is printed on a FR4 substrate material. The operating bandwidth and maximum gain of the antenna are 110% (3.1 – 10.8 GHz) and 5.1 dB, respectively. Tan et al. [14] designed a modified UWB antenna with a gain enhancement for wireless applications on a FR4 substrate. The patch of the antenna is embedded with slots to increase radiation characteristics and ensure a wide impedance bandwidth. To provide proper impedance matching over a wide frequency range, two rectangular ring slots are inserted in the ground plane. The antenna has a total size of 55 mm × 56 mm × 1.6 mm and is

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fabricated on a low-cost FR4 substrate. The analysis shows that an impedance bandwidth ranging from 2.2 GHz to more than 12 GHz, which is equal to 138% fractional bandwidth, is achieved with a maximum gain of more than 6.5 dB.

Elajoumi et al.[15] demonstrated that a compact microstrip rectangular antenna with a defected ground structure (DGS) with different positions of the additional patch in the ground can be used to improve bandwidth for UWB applications. The total size of the antenna is 26 mm × 30 mm × 1.6 mm and is designed on a low-cost FR4 substrate. An improved bandwidth of 3 to 15 GHz (133.33%) with a gain of 1.5 – 4.8 dB is shown. Gain enhancement for the exposure system of a rectangular microstrip patch antenna designed with a microstrip array was described by R.D. Mishra and P.K. Singha [16] in order to achieve a gain of 2.8647 – 5.6692 dB. According to Xiong et al.[17], an enhanced ultra-wideband (UWB) and a high gain rectangular antenna were explicitly designed using planar-patterned metamaterial principles. Isolated triangle gaps and crossed gaps are inserted into the antenna's metal patch and ground plane. The size of the antenna is 27.6 × 31.8 mm^2 and is printed on an F4BM-2 substrate with a thickness of 0.8 mm and a permittivity of 2.2. The antenna achieves broad bandwidth ranging from 3.85 – 15.62 GHz and an average gain of 5.42 dB, with a peak gain of 8.36 dB.

Roy et al. [18] designed a rectangular patch with a width (W) of 32 mm and a length (L) of 24 mm by combining three different geometry shapes, U, E, and H. Alumina 96% is used as the substrate material of the antenna, with a dielectric constant of 9.4 and a loss tangent of 4.0e-4, and it was simulated using Sonnet software. The increase in bandwidth was 4.81% (100 MHz) to 28.71% (610 MHz) for U-shaped patch antenna, 28.89% (630 MHz) for E-shaped patch antenna, and 9.13% (110 MHz) for H-shaped patch antenna. Y. Sung [19] describes how to use a parasitic center patch to increase the bandwidth of a microstrip line-fed printed wide-slot antenna. The antenna, which consists of a rotating square slot and a parasitic patch, is designed on FR4 dielectric substrate with a permittivity of 4.4 and a thickness of 1.6 mm that is commercially available. As a result, an impedance bandwidth of 3.12 GHz (2.23 to 5.35 GHz) and a maximum gain of 4 dB were obtained.

The authors of [20] described a CPW-fed slot antenna on FR4 substrate that can resonate at 5GHz with a gain ranging from -0.98 dB to 4.62 dB. Zhao et al. [21] illustrated a wideband and high gain circularly polarized ultra-high-frequency (UHF) RFID reader microstrip antenna and array with a gain of 9.7 dBi. Lin et al. [22] presented a new design for radio-frequency identification (RFID) tag antenna mounted on a metallic plane with a peak gain of 8.7dBi. In the design of a low-profile two-arm spiral antenna, a circularly symmetric high-impedance surface (HIS) was used as a ground plane [23]. A 11.3% fractional bandwidth is achieved, as well as a maximum gain of 2.5 dB. Rusdiyanto et al. [24] proposed a microstrip antenna design for bandwidth and enhancement purposes that is based on the defected ground structure (DGS) and horizontal patch gap (HPG). The antenna achieved a bandwidth of 764.4 MHz and a gain of 2.8 dBi.

Raviteja et al. [25] investigated the use of U and Quad L-shaped slots with L-shaped DGS and U-shaped dual parasitic elements. This antenna has a bandwidth of 1.40 GHz and a gain of 7.2 dB. A. Swetha and K. R. Naidu [26] introduce a novel semi-circular ultra wide-band antenna for broadband applications that was inspired by a complementary split-ring resonator for bandwidth enhancement and a frequency selective surface reflector for gain enhancement, achieving a large bandwidth of 130.3 percent from 3.16 to 15 GHz and gain ranging from 4.9 dB to 10.9 dB. A simple low-profile defected ground structure-based monopole circular-shaped patch antenna for ultra-wideband applications was developed by Gopil et al. [27]. The antenna has an impedance bandwidth of 8.1GHz (2.5 – 10.6 GHz). For the two resonant frequencies, the gains are 8.4 dBi and 8.2 dBi, respectively. A rectangular microstrip patch antenna was designed by Kharusi et al. [28] for gain improvement using the air gap technique. The gain is increased from 6.907 dB to 9.179 dB based on the simulation results. E. K. I. Hamad and G. Nady [29] used metamaterial (MTM) double-side planar periodic structures to design a compact extended bandwidth UWB microstrip antenna. The antenna has a wide bandwidth of 3.2 to 23.9 GHz and a peak gain of 6.2 dB at 8.7 GHz.

III. ANTENNA DESIGN

The proposed rectangular microstrip patch antenna (RPMA) without and with slots are shown in Fig. 2, those are designed on FR4 dielectric substrate, having thickness of 0.8 mm with relative permittivity of 4.4 and the tangent loss of 0.02. The designed antenna is 30 mm × 20 mm in size. To excite the patch, the microstrip feed line is used with a characteristic impedance of 50 Ω. The RPMA without slots provides a narrow bandwidth of 3.68 GHz (3.24 GHz – 6.92 GHz) and a maximum gain of 5.06 dB, which are shown in Fig. 3(a) and (b). In order to increase the antenna bandwidth and gain, rectangular- right angle triangular slots are inserted into the patch and a single rectangular slot is added into the top edge of the partial ground plane. The various optimized parameters of the proposed antenna are mentioned in Table 1. The parameters have been obtained after several series of optimizations using HFSS.

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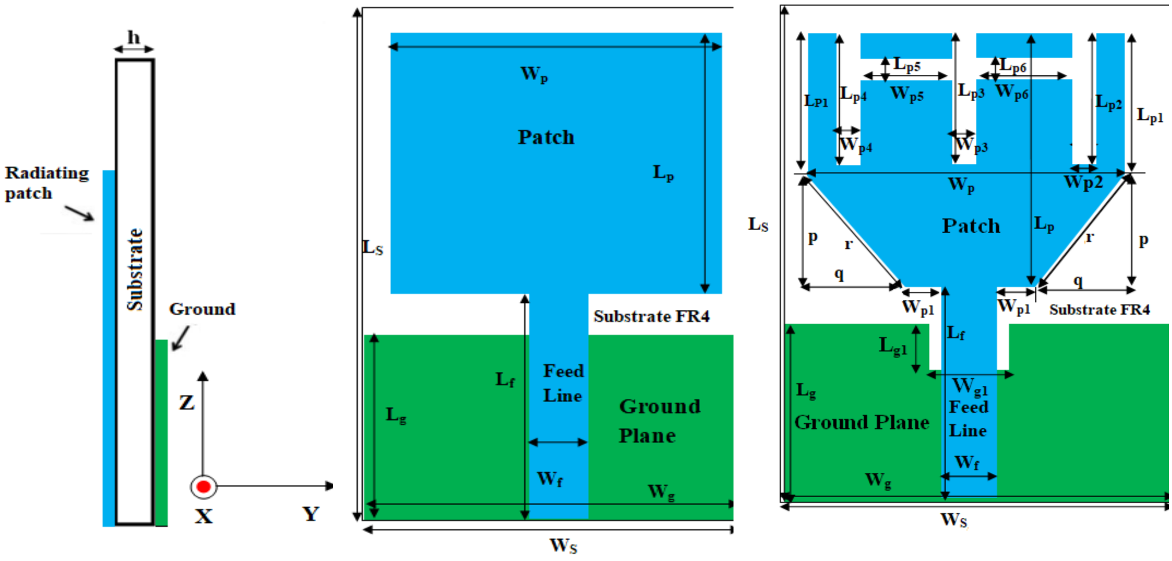

(a) Side view (b) RPMA without slots (c) RPMA with slots

FIGURE 2. Design of the proposed rectangular patch microstrip antenna (RPMA).

TABLE 1. Design parameters value of the proposed antenna.

Parameters	Values (mm)	Parameters	Values (mm)
$W_S = W_g$	20	L_{g1}	3
L_S	30	L_{p1}	8
h	0.8	$L_{p5}=L_{p6}=W_{p2}=W_{p3}=W_{p4}$	0.5
W_P	18	$L_{p2}=L_{p3}=L_{p4}$	7
$L_P = L_g$	14	$W_{p5}=W_{p6}$	6.5
L_f	15	p = q	6
$W_f=W_{g1}=W_{P1}$	2	r	8.48

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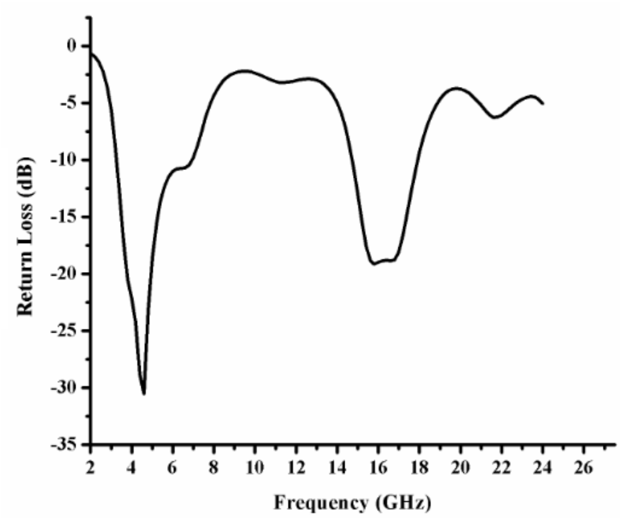
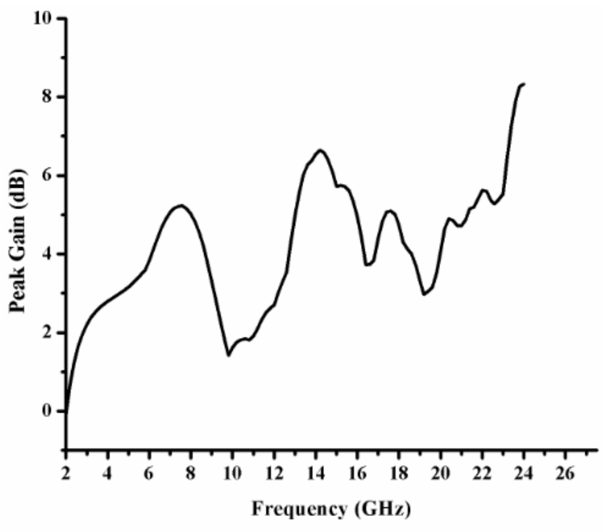


(a) Bandwidth of RPMA without slots



(b) Peak gain of RPMA without slots

FIGURE 3. Bandwidth and peak gain of rectangular microstrip patch antenna (RPMA) design without slots.

IV. RESULTS AND DISCUSSIONS

The proposed antenna is simulated using Ansoft HFSS, and its numerical analysis is based on the finite element method. The bandwidth of an antenna is defined as the frequency range within which the performance of the antenna integrates to a specified standard with respect to certain characteristics. From the return loss graph, it can be calculated within the entire frequency range where the return loss remains below -10 dB.

The bandwidth of the rectangular patch microstrip antenna (RPMA) without and with slots is shown in Fig.4. We can observe from the figure that the RPMA without slots consists of two bands (3.24 – 6.92 GHz, and 14.69 – 17.91 GHz). The first band is of 3.68 GHz bandwidth (bandwidth percentage of 72.44%) and the graph clearly shows that the good performance of the antenna is at 4.55 GHz frequency where the return loss is - 30.40 dB. The rectangular patch microstrip antenna (RPMA) with slots i.e. the slotted RPMA has an overall bandwidth of 19.7 GHz (3.15 GHz – 22.85 GHz) with nine resonance frequencies of 3.5 GHz, 6.3 GHz, 6.8 GHz, 7.7 GHz, 11.7 GHz, 15 GHz, 17.7GHz, 20 GHz, and 21.8 GHz and the graph also demonstrates that the good performance of the slotted RPMA is at 7.7 GHz with return loss of -28.35 dB. However, approximately 5.35 times wider bandwidth has been achieved compared to the RPMA without slots is shown in Fig. 4.

The different resonant frequencies of the proposed antenna can be used in various applications such as WiMAX technology (3.4 – 3.69) GHz, STM band applications (6 – 6.17 GHz), uplink (5.925 - 6.425 GHz) satellite communication, WLAN applications (5.15 – 5.825 GHz), radio astronomy applications (5.01 – 5.03 GHz), WiMAX (5.25 – 5.85 GHz) and C-band (4 – 8 GHz), downlink X-band satellite communication (7.25 – 7.75 GHz), and fixed-satellite service from space to earth (10.7 – 11.7 GHz), X-band (8 – 12 GHz) applications, amateur radio operations (10-10.5 GHz) and amateur satellite operations (10.45 – 10.5 GHz), and Ku band (12 – 18 GHz) applications.

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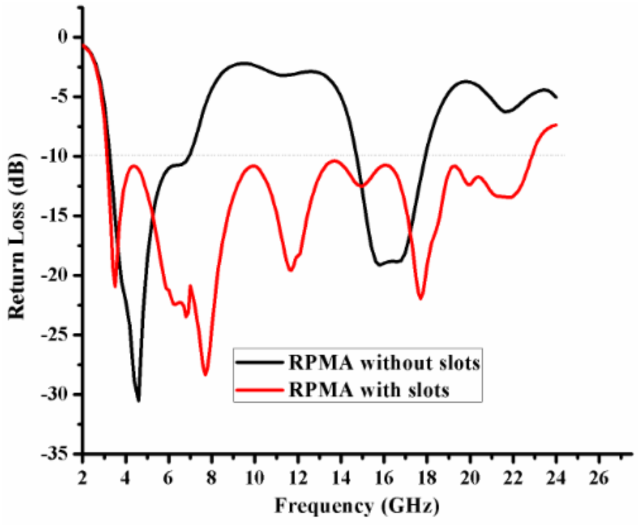

FIGURE 4. Comparison of return loss graphs of the rectangular patch microstrip antenna (RPMA) without and with slots.

Gain is a measure of the capability of an antenna to concentrate the transmitted energy in a specific direction. The peak gain plot of the rectangular microstrip patch antenna (RPMA) without slots and rectangular microstrip patch antenna (RPMA) with slots is shown in Fig.5. The gain of the slotted rectangular patch microstrip antenna (SRPMA) increases as the frequency increases. Because of the shorter wavelength at high frequencies, the effective area of the antenna increases. It is clearly noticeable from the figure that the peak gain of the SRPMA is 8.06 dB means that 5.5 times the amount of effective power will be sent in the direction of a target than from an isotropic radiator, and so has the equivalent effect of eight times the power of the transmitter in that particular direction, while the peak gain of the RMPA is 5.06 dB means that 3.50 times more effective power is sent in the direction of a destination than from an isotropic radiator, and thus has the equal impact of 3.50 times the energy of the transmitter in that specific direction. From the above gain discussion, it is clear that the gain of the slotted RPMA is 3 dB greater than that of the rectangular patch microstrip antenna (RPMA).

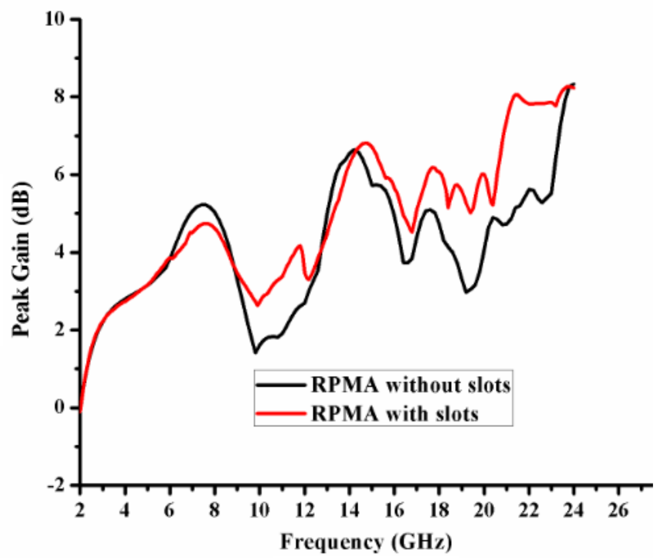

FIGURE 5. Comparison of peak gain graphs of the rectangular patch microstrip antenna (RPMA) without and with slots.

Figure 6(a) and (b) depict a simulated 2D view of the far-field radiation pattern of a rectangular patch microstrip antenna (RPMA) without and with slots at 6.85 GHz, respectively. The radiation patterns of the antenna in the E-plane

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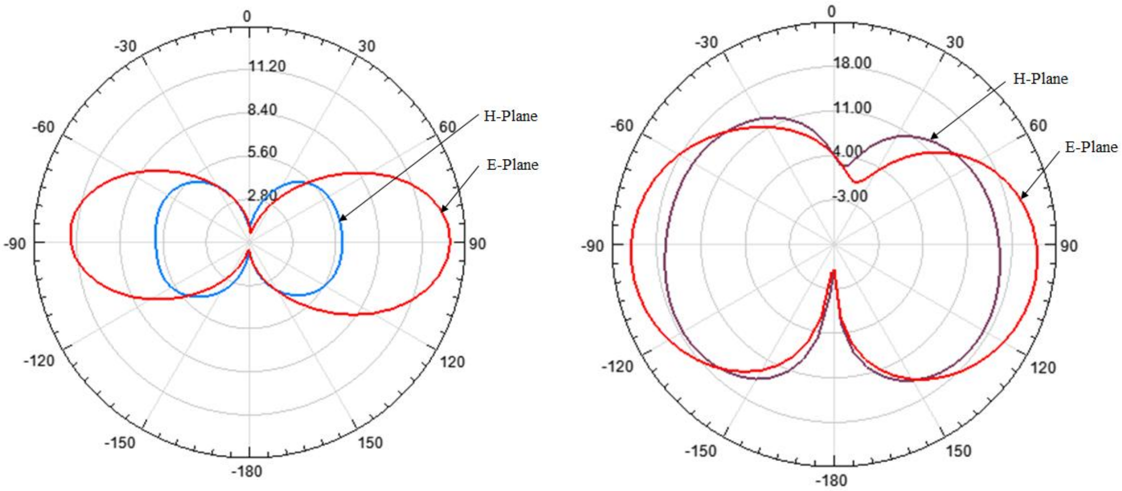
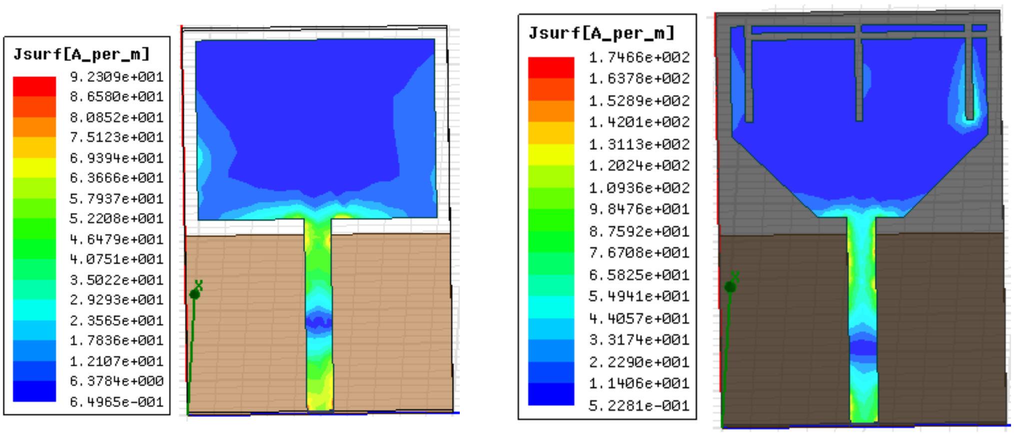
and H-plane are similar to those of a dipole antenna at the resonance frequency of 6.85 GHz.



(a) Radiation pattern of RPMA without slots (b) Radiation pattern of RPMA with slots

Figure 6. 2D view of the far field radiation pattern of rectangular patch microstrip antenna (RPMA) design.

The effects of a rectangular patch microstrip antenna (RPMA) without slots are investigated. The surface current distribution density of the RPMA without slots is simulated at 6.85 GHz and is shown in Fig. 7(a). Similarly, the surface current distribution density of the RPMA with slots is simulated at 6.85 GHz and is shown in Fig. 7(b).The current flow of the RPMA with slots at 6.85 GHz is found to be greater than the current flow of the RPMA without slots based on the current surface distribution. This enhances the antenna's capacity and gain.



(a) Surface current distribution of RPMA without slots (b) Surface current distribution of RPMA with slots

FIGURE 7. Distributions of surface current of rectangular patch microstrip antenna (RPMA) at 6.85 GHz.

A comparison of the bandwidth, bandwidth percentage, and gain of the proposed rectangular patch microstrip antenna (RPMA) without slots and with slots is shown in Table 2. From the table it is seen that the bandwidth of the RPMA with and without slots is 19.7 GHz and 3.68 GHz respectively. Bandwidth increases from 3.68GHz to 19.7 GHz. There is a 79.1% improvement in bandwidth. The gain of the RPMA with and without slots is 5.06 dB and 8.06 dB, respectively i.e. there is an increase of 3 dB in gain for the slotted patch antenna. It is clear from Table 2 that, the

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bandwidth and gain of the proposed RPMA with slots has been improved significantly as compared to the RPMA without slots.

TABLE 2. Comparison of bandwidth, bandwidth percentage and gain of the proposed rectangular microstrip patch antenna (RPMA) without and with slots.

Parameters	RPMA without slots	RPMA with slots	Improvement factor
Bandwidth	3.68 GHz (3.24 GHz – 6.92 GHz)	19.7 GHz (3.15 GHz – 22.85 GHz)	16.02 GHz
Bandwidth percentage	72.44%	151.54%	79.1 %
Gain	5.06 dB	8.06 dB	3 dB

VI.CONCLUSION

The main disadvantages of the microstrip patch antenna are its restricted bandwidth and low gain, which limit its application. The proposed antenna overcomes these implicit constraints by including rectangular-right angle triangle-shaped slots on the patch and a single rectangular shaped slot on the partial ground plane. This designed antenna improves both bandwidth and gain. The analysis shows that the bandwidth of the rectangular patch microstrip antenna without slots (conventional antenna) has increased from 72.44% to 151.54%, which means 79.1% improvement in bandwidth by using slots into the patch-partial ground plane. The gain has also improved from 5.06 to 8.06 dB.

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