SSRG International Journal of Recent Engineering Science
ISSN: 2349–7157 / https://doi.org/10.14445/23497157/IJRES-V8I5P102

Volume 8 Issue 5, 6-12, Sep-Oct, 2021

Original Article

Design of a Ultra-Wideband Rectangular Patch Microstrip Antenna with Improved Bandwidth

M. Firoz Ahmed[1], Abu Zafor Md. Touhidul Islam[2] and M. Hasnat Kabir[3]

[1,3]*Department of Information and Communication Engineering, University of Rajshahi, Rajshahi, Bangladesh.*
[2]*Department of Electrical and Electronic Engineering, University of Rajshahi, Rajshahi, Bangladesh.*

Received: 20 August 2021 Revised: 25 September 2021 Accepted: 07 October 2021 Published: 17 October 2021

Abstract *- In wireless communication systems, patch antennas are most commonly used. A primary disadvantage of the patch antennas is their restricted bandwidth (<5%). This paper presents the design of a rectangular patch microstrip antenna for UWB applications using the partial ground plane technique with a single rectangular slot on the upper edge of the partial ground plane and right-angle triangular slots on the lower corners of the patch, which has been designed to overcome this impediment. The suggested design has an impedance bandwidth of 19.91 GHz around the six resonance frequencies of 3.4 GHz, 6.2 GHz, 8 GHz, 11.40 GHz, 17.40 GHz, and 21.40 GHz. This is about 13.54 times higher than the bandwidth of a traditional rectangular patch antenna (bandwidth =1.47 GHz). This antenna can be used in a wide variety of wireless applications such as X band, C-band, Ku band, S-band, STM band, WiMAX, WiFi, WLAN, radio astronomy, military communications, communications and sensors, positioning and monitoring, radar and satellite communication applications. HFSS simulation software has been used for the simulation of the propounded design.*

Keywords *- Rectangular patch antenna, Rectangular slot, Right angle triangular slots, Ultra-wideband (UWB).*

1. Introduction

Researchers are interested in microstrip patch antennas (MPAs) due to their numerous advantages, including low profile structure, lightweight, conformal shape, cost-effectiveness, high efficiency, ease of installation, small volume, and compatibility with integrated microwave circuits (MICs) and monolithic microwave integrated circuits (MMIC) [1,2]. Patch antennas are commonly used in radar, satellite, and mobile communications because of these properties. Nevertheless, MPAs have a severe constraint in the form of relatively low impedance bandwidth, which is typically around 5% of the center frequency bandwidth. In the last two to three decades, research has been conducted to enhance the bandwidth of patch antennas. These bandwidth improvement methodologies include the use of frequency-selective surfaces [3, 4], low dielectric substrates, multiple resonators, thicker substrates [5], stacked configurations [6], and slot antenna geometry [7, 8]. A T-slot rectangular patch antenna is presented in [9]. The -10 dB impedance bandwidth is 25.23%. A 21.62% bandwidth S-shaped microstrip patch antenna is demonstrated [10]. To enhance bandwidth, the researchers suggest a wideband gap-coupled slot rectangular microstrip array antenna for broadband applications [11]. The antenna has a bandwidth of 26.72%. A square patch antenna with modified edges and square fractal slots with a bandwidth of 30% is designed in [12]. In [13], the authors proposed a slotted U-shaped microstrip antenna with PBG geometry. A 35% impedance bandwidth is seen in the simulation result. A microstrip patch antenna with a 44 percent bandwidth is constructed in [14] using a combination of crown and sierpinski fractal slots. Gupta et al. [15] illustrated that two, three, and six slit-slotted circular patch antennas could achieve impedance bandwidths of 63.3%, 72.10%, and 37.5%, respectively. Elajoumi et al. [16] used a defective ground structure (DGS) with different locations of the extra patch in the ground to create a tiny microstrip rectangular antenna with a bandwidth of 133.33 percent for UWB applications. Mondal and Sarkar [17] propose incorporating an M-shaped radiating patch with a U-shaped slot on the ground plane to increase the bandwidth of a microstrip patch antenna with a bandwidth of 99.9%. A defected ground structure method (DGS) rectangular microstrip patch antenna with an improved bandwidth of 5.3% is described in [18]. In [19], the authors report a gap-coupled modified square fractal microstrip patch antenna with an impedance bandwidth of 85.42%. A compressed enhanced bandwidth UWB microstrip antenna is developed to use metamaterial (MTM) double-side planar periodic structures [20]. The bandwidth of the antenna ranges from 3.2 to 23.9 GHz, with a maximum gain of 6.2 dB at 8.7 GHz. A method for increasing the bandwidth of a microstrip patch antenna by using a large number of ground plane slots was proposed in [21]. The slotted antenna has a frequency range of up to 540MHz. Increasing microstrip patch antenna bandwidth by inserting ground slots is introduced in [22], and simulation results indicate an 18% increase in antenna bandwidth. The design of a rectangular patch microstrip antenna for wide bandwidth using left-handed metamaterial (LHM) is presented in [23]. Simulation results, the use of the LHM structure can improve bandwidth up to 175.7 MHz, with a bandwidth enhancement of 213.75 percent greater than without the LHM. The use of a metasurface coupled to a microstrip patch antenna for bandwidth improvement is demonstrated in [24]. The bandwidth of the antenna is between 5.1 and 8.0 GHz. In [25], the deteriorated ground plane method is used to calculate the bandwidth enhancement of a conventional inset-fed rectangular microstrip patch antenna. In [26], a slotted array technique is used to improve the bandwidth and gain of a rectangular microstrip patch antenna (RMPA). The bandwidth and gain of a traditional microstrip patch antenna are increased from 4.66 percent to 10.22 percent and 6.92 dB to 19.88 dB, respectively, according to the findings. The compact and slotted patch antenna geometry in [27] is designed to improve bandwidth. The antenna has a 62.9 percent impedance bandwidth (1910 MHz). The corner truncation technique is proposed in [28] for increasing the bandwidth of the rectangular patch antenna. A bandwidth of 9147.4 MHz is achieved by this antenna. In [29], a microstrip patch antenna design for ultra-wideband applications that improve bandwidth by slotting the feedline, incorporating a curved slot in the patch, and changing the patch shape is presented.

The impedance bandwidth (defined by -10 dB return loss) obtained from this antenna is 9.1(2 - 11.1) GHz, according to the simulated results. To boost bandwidth, [30] presents a low-profile substrate with a waveguide-based circular-shaped cavity-backed antenna. With cylindrical- and rectangular-shaped dielectric resonators, the antennas have an impedance bandwidth of 750 MHz, which represents a bandwidth enhancement of 700 MHz in both cases and an impedance bandwidth of 710 MHz with hemispherical-shaped dielectric resonators, which represents a bandwidth improvement of 660 MHz in both cases. Raviteja et al. [31] studied the use of U and Quad L-shaped slots and also L-shaped DGS and U-shaped dual parasitic elements. The bandwidth of this antenna is 1.40 GHz, and the gain is 7.2 dB. The use of metamaterials to improve the gain and bandwidth of an ultra-wideband microstrip antenna is described in [32]. According to the study, an increased bandwidth of 2.6 - 20 GHz with a gain of 5.6 dB is possible. In [33], a microstrip antenna design based on the defective ground structure (DGS) and horizontal patch gap (HPG) is intended to enhance bandwidth and gain. The antenna has a 2.8 dBi gain and a bandwidth of 764.4 MHz. A miniaturized mace-shaped ground plane altered circular patch antenna for ultra-wideband applications is proposed [34].

The highest gain and fractional bandwidth of this antenna, according to simulation results, are 3.2dB and 118 percent (3.1 to 12.13 GHz), respectively. The authors of [35] propounded a tiny stepped slot antenna for ultra-wideband (UWB) applications. The antenna's impedance bandwidth ranged from 3.05 GHz to more than 12 GHz. The notched-band characteristics of a very small ultra-wideband (UWB) slot antenna with three L-shaped slots are analyzed in [36]. According to the simulation results, the antenna has an impedance bandwidth ranging from 2.65 to 11.05 GHz. A new and informative study into a compact-size ultra-wide-band (UWB) microstrip antenna for DS-UWB applications is demonstrated [37]. The simulation result showed a 109 percent impedance bandwidth. A low-profile monopole circular-shaped patch antenna based on a defected ground structure for ultra-wideband applications is explained in [38]. The impedance bandwidth of the antenna ranges between 2.5 and 10.6 GHz. Gains of 8.4 dBi and 8.2 dBi are seen at the two resonant frequencies. The center frequency and notched bandwidth of a compact ultra-wideband (UWB) antenna are adjusted using a modified patch and electromagnetic band gap (EBG) structure [39]. According to the analysis, the enhanced bandwidth is 3.1 - 12.5 GHz, with the largest gain of 4.5 dBi.

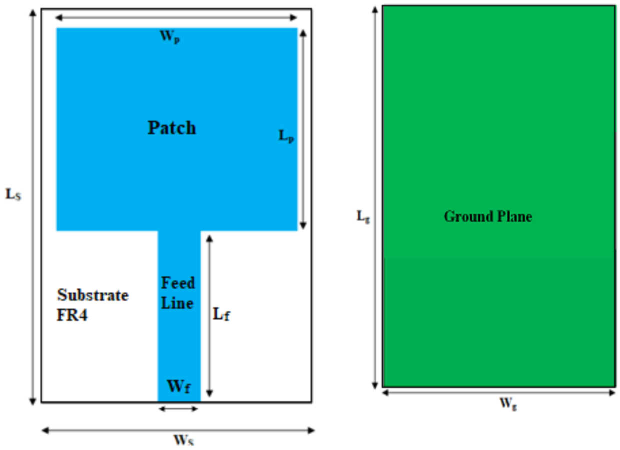
Two steps are used to design a rectangular patch microstrip antenna for UWB applications in this paper. A conventional antenna with a full ground plane is designed in the first step. In the second step, a combination of partial ground with a single rectangular slot inserted on the upper edge of the partial ground plane and right-angle triangular slots inserted on the patch's lower corners is planned. The goal is to improve the bandwidth performance of the antenna.

Partial ground reduces the amount of energy stored in the substrates. The decrease in quality factors (Q) is caused by a decrease in energy storage in the substrates. The bandwidth increases as the Q factor decreases. Back radiation is a result of a partial ground plane. Hence, there will be a greater loss of radiation. As a result, the Q factors decrease, and the bandwidth increases. Slots reduce the value of return loss and VSWR of the antenna. These slots also reduce the size of the antenna, resulting in low-quality factors and, therefore, increased gain and bandwidth.

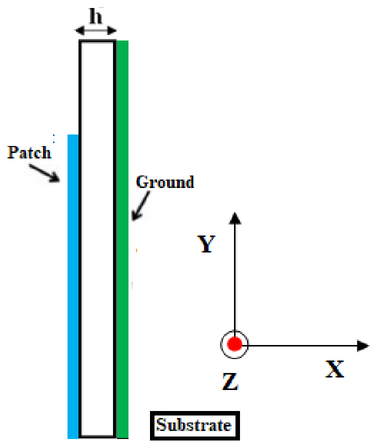
2. Proposed Antenna Design

2.1. Step One: Conventional Rectangular Patch Microstrip Antenna Design

Fig. 1 illustrates the geometry of a conventional rectangular patch antenna with the full ground plane. This geometry is designed on an FR4 substrate with a dielectric constant (ε_r) of 4.4, a thickness (h) of 0.8mm, and a loss tangent (tanδ) is 0.02. A microstrip feed line is used to excite the patch with a characteristic impedance of 50Ω. The various parameters of a conventional rectangular patch antenna are shown in Table I.



(a) (b)



(c)

Fig. 1 Geometry of the conventional rectangular patch microstrip antenna (a) Top view (b) Bottom view (c) Side view

Table 1. Geometrical parameters of a conventional rectangular patch antenna

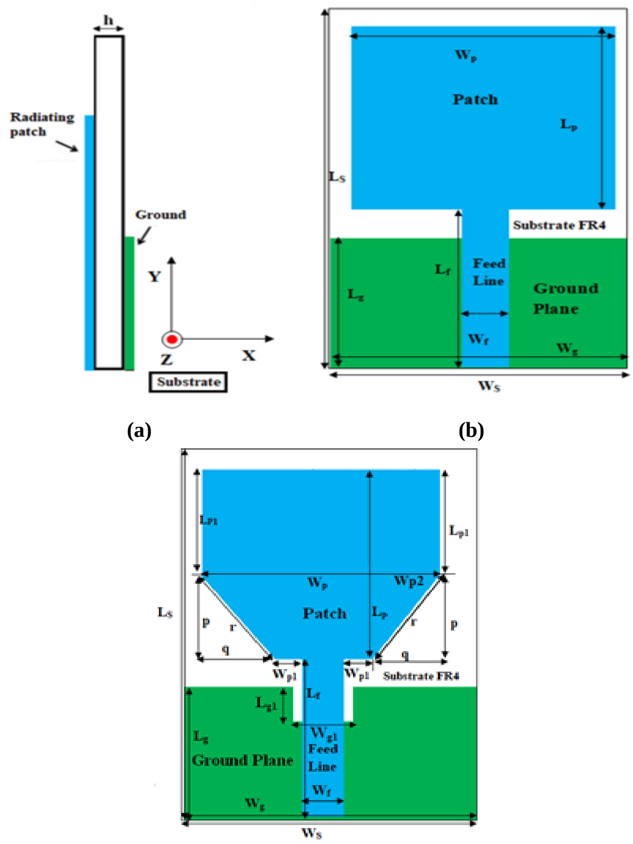
Parameters	Value	Parameters	Value
Patch width, W_P	18 mm	Ground plane width, W_g	20 mm
Patch length, L_P	14 mm	Ground plane length, L_g	30 mm
Substrate width, W_S	20 mm	Thickness, h	0.8 mm
Substrate length, L_S	30 mm	Relative permittivity, ε_r	4.4
Microstrip feedline width, W_f	2 mm	Operating frequency	6.85GHz
Microstrip feedline length, L_f	15 mm	Dielectric loss tangent	0.02

2.2. Step Two: Rectangular Patch Microstrip Antenna Design with Slots using the Partial Ground Technique

The geometry of a rectangular patch microstrip antenna with slots that uses a partial ground plane technique is depicted in Fig. 2. In this case, a partial ground plane dimension (W_g * L_g) of 20 mm*14 mm, a single rectangular slot inserted on the partial ground plane's upper edge, and right-angle triangular slots inserted on the patch's lower corners has been used to increase the bandwidth of the antenna. Other dimensions of the antenna are the same as the conventional antenna. Table II shows the different optimized parameters of the proposed antenna. The parameters were obtained through a series of HFSS optimizations.

3. Simulation Results and Discussion

This section describes the simulated performance metrics of the proposed antenna, such as return loss, bandwidth, gain, and radiation pattern. The High-Frequency Structure Simulator (HFSS) version 15, which is based on the Finite Element Method (FEM), has been used to assess all of the parameters.



(c)

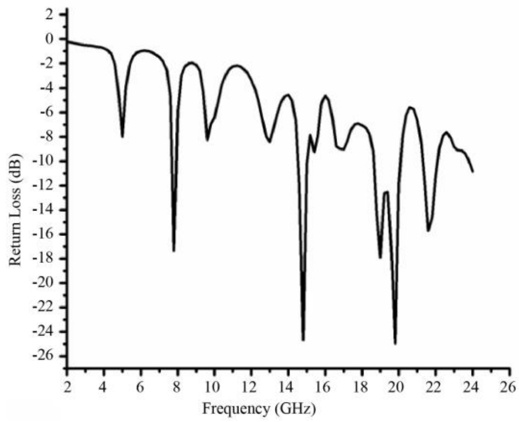
Fig. 2 Geometry of the proposed antenna (a) Side view, (b) Patch antenna with the partial ground, and (c) Final design

Table 2. Geometrical parameters of the proposed rectangular patch antenna

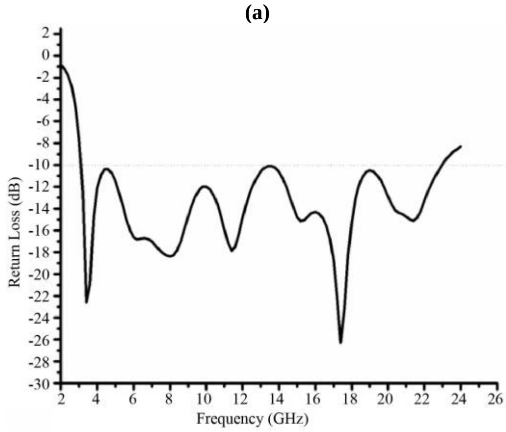
Parameters	Value	Parameters	Value
Partial ground width, W_g	20 mm	Patch width, W_{P1}	2 mm
Partial ground length, L_g	14 mm	Patch length, L_{P1} = p	7 mm
Ground slot width, W_{g1}	2 mm	q	6mm
Ground slot length, L_{g1}	3 mm	r	9.23mm

The S11 parameter explains the relationship between the antenna system's terminals and input-output ports, and it is also known as the return loss of the proposed antenna. The S11 parameter represents the amount of power reflected back from the antenna's input port, as well as the remaining power that is radiated by the antenna. For the antenna to operate effectively in practical applications, the return loss must be less than or equal to -10 dB for a specific frequency band. The return loss versus frequency plot of the conventional antenna with a full ground plane is shown in Fig. 3 (a). The antenna exhibits multiband behavior and operates on four resonant frequencies: 7.80 GHz, 14.8 GHz, 19.80 GHz, and 21.6 GHz, with return losses of -17.37 dB, -24.66 dB, -24.98 dB, and -15.7 dB, respectively. However, the antenna with a full ground plane does not work on the resonant frequency for which it was designed, and it also has a very limited bandwidth of a few MHz throughout all frequency bands. The conventional patch antenna also has good performance at 19.80 GHz frequency, with a return loss of -24.98 dB, as shown in the figure.

To increase bandwidth and make the antenna work at the appropriate resonant frequency, a partial ground plane method is used, with a single rectangular slot added to the top edge partial ground plane and right-angle triangle slots inserted into the bottom corners of the patch. The return loss versus frequency plot of the proposed antenna is illustrated in Fig. 3(b). The proposed patch antenna has a return loss of -22.60 dB at 3.4 GHz, -16.82 dB at 6.2 GHz, -18.38 dB at 8 GHz, -17.88 dB at 11.40 GHz, -26.30 dB at 17.40 GHz and -15.16 dB at 21.40 GHz, as shown in Fig. 3(b). In addition, the figure indicates that the proposed rectangular patch antenna operates well at 17.40 GHz, with a return loss of -26.30 dB. A negative return loss result implies that there were few losses while transmitting the signals by this antenna. As a result, the suggested microstrip patch antenna has a return loss of 5.28% less than a traditional microstrip patch antenna. Figs. 3 (a) and (b) can be used to compute the antenna bandwidth. A typical patch antenna's bandwidth (BW) and fractional bandwidth (FBW) are 1.47 GHz and 7.59%, respectively, with a return loss of -10 dB, but the intended antenna's bandwidth (BW) and fractional bandwidth (FBW) are 19.91 GHz and 152.62%. When compared to a traditional antenna, the bandwidth has been enhanced by 13.55 times.



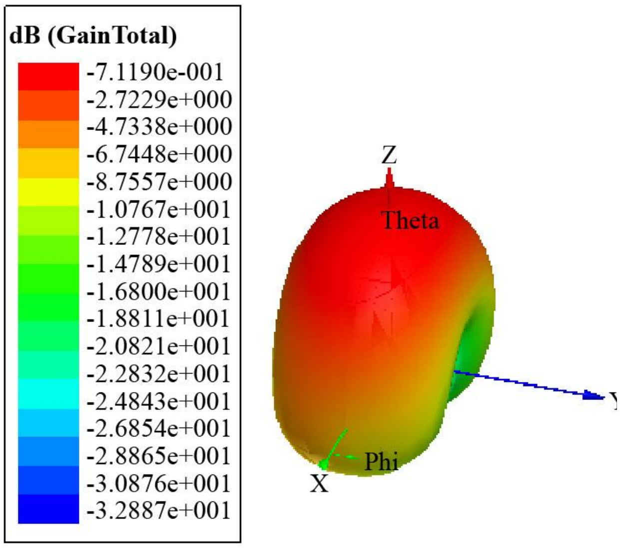
(a)



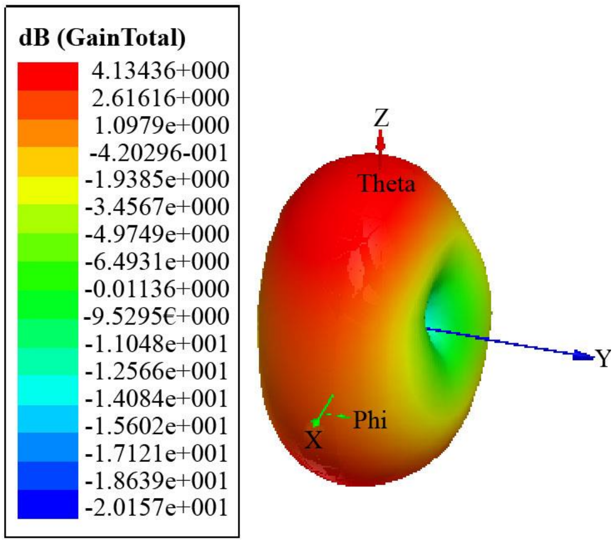
(b)

Fig. 3 Return loss versus frequency plot of (a) the conventional antenna with full ground plane and (b) the proposed antenna

A gain of the antenna can be used to indicate or study the directional capabilities of the antenna, and it is denoted in decibels. The simulated results for 3D gain obtained from the conventional antenna and the proposed antenna are shown in Figs. 4 (a) and (b). The conventional antenna and the proposed antenna have a maximum gain of -0.7119 dB and 4.1343 dB, respectively, at the operating frequency of 6.85 GHz. As a result, the gain of the proposed patch antenna is 5.71 times greater than the traditional patch antenna.



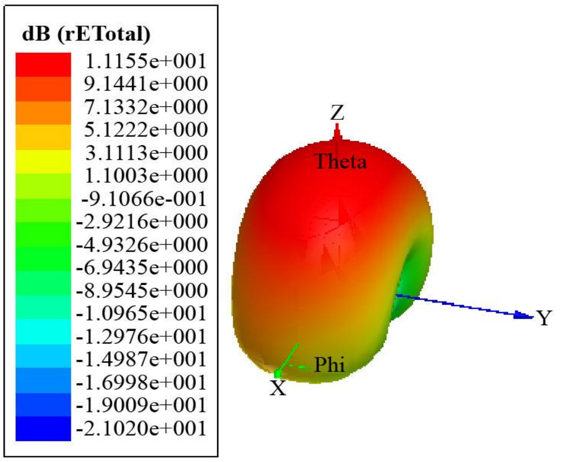
(a)



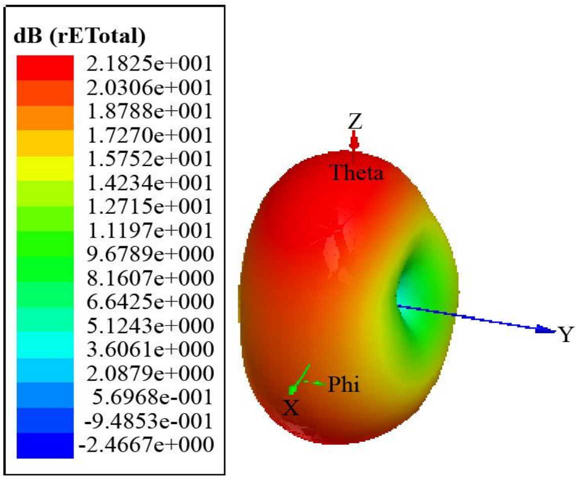
(b)

Fig. 4 Simulated 3D gain at 6.85GHz (a) conventional antenna (b) proposed antenna

The radiation pattern of the antenna characterizes the radiated energy. Figs. 5 (a) and (b) show a simulated 3D view of the far-field radiation pattern of the conventional antenna and the proposed antenna at the resonant frequency of 6.85 GHz, respectively. The red color denotes the most radiation, while the blue color denotes the lowest radiation, and the yellow and green colors show the ranges in between. The radiation pattern approximates that of a dipole antenna very closely. This indicates omnidirectional radiation, with a maximum power of 11.155 dB for the traditional antenna and 21.825 dB for the proposed antenna, indicating a considerable advantage in ultra-wideband (UWB) communication systems.



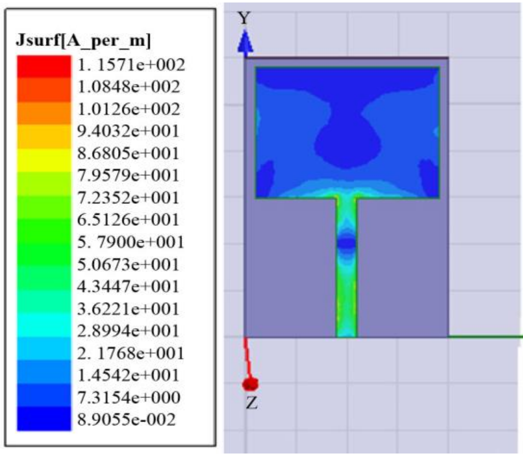
(a)



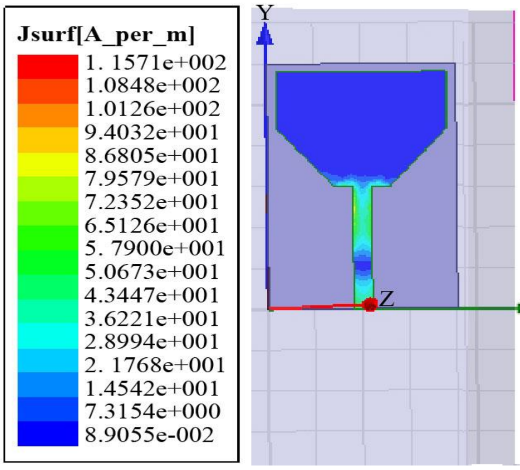
(b)

Fig. 5 Simulated 3D view of radiation pattern for: (a) conventional rectangular patch antenna (b) proposed patch antenna

The implications of a basic antenna (conventional antenna) are studied. At 6.85 GHz, the surface current distribution density of this antenna is simulated, as shown in Fig. 6 (a). Similarly, at 6.85 GHz, the surface current distribution density of the proposed antenna is simulated and shown in Fig. 6 (b). Based on the current surface distribution, the current flow of this antenna at 6.85 GHz is found to be larger than the current flow of the conventional antenna. This increases the capacity and gain of the antenna.



(a)



(b)

Fig. 6 Surface current distributions of rectangular patch microstrip antenna at 6.85 GHz (a) conventional antenna (b) proposed antenna

A comparison of the performance of a few newly developed antennas for UWB applications with the proposed antenna is shown in Table III. The impedance bandwidth of our designed antenna is 19.91 GHz (3.05 GHz – 23 GHz). By comparing various parameters, it is possible to conclude that the proposed antenna significantly improves bandwidth. The bandwidth in this study is nearly identical to that in ref. [20]. It is possible that not only the design mechanism but also the antenna size has an effect on the improvement of bandwidth.

Table 3. Comparisons of the preceding and present designed rectangular microstrip patch antennas

Reference No's	Antenna Size, (mm^3)	Operating Bandwidth (GHz)	Bandwidth (GHz)	Bandwidth (%)
[20]	32 × 27.6 × 1.6	3.2 – 23.9	20.7	152.76
[32]	36 × 38 × 1.58	2.6 – more than 20	17.4 (approx.)	153.98
[34]	14 × 18 × 1.6	3.1 – 12.13	9.03	118
[38]	48 × 38 × 1.6	2.5 – 10.6	8.1	123.66
[39]	16 × 25 × 1.52	3.1–12.5	9.4	120.51
This work	30 × 20 × 0.8	3.09 – 23	19.91	152.62

4. Conclusion

In this article, a new rectangular patch microstrip antenna with slots has been designed and investigated using the partial ground approach for UWB applications. After employing a partial ground methodology with a single rectangular slot added on the top edge of the partial ground plane and right-angle triangular slots embedded on the patch's lower corners, the proposed antenna's bandwidth (BW) and fractional bandwidth (FBW) have been found to be increased. The proposed antenna also achieved BW and FBW of 19.91 GHz and 152.62% at the six resonance frequencies of 3.4 GHz, 6.2 GHz, 8 GHz, 11.40 GHz, 17.40 GHz, and 21.40 GHz, respectively, whereas a conventional patch antenna with full ground achieves BW and FBW of 1.47 GHz and 7.59%, respectively, according to the simulation results of this study. In comparison to a conventional patch antenna, the BW increased by 1354.42% from 1.47 GHz (18.61 GHz - 20.08 GHz) to 19.91 GHz (3.09 GHz - 23 GHz).

References

[1] P. Kumar, and G. Singh, "Gap-Coupling: A Potential Method for Enhancing the Bandwidth of Microstrip Antennas," *Advanced Computational Techniques in Electromagnetic*, vol. 2012, pp. 1- 6, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[2] Constantine A. Balanis, *Antenna Theory, Analysis, and Design*, John Wiley & Sons, 2005.[Google Scholar]

[3] Hsing-Yi Chen, and Yu Tao, "Performance Improvement of a U-slot Patch Antenna Using A Dual-Band Frequency Selective Surface with Modified Jerusalem Cross Elements," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 9, pp. 3482-3486, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[4] Hsing-Yi Chen, and Yu Tao, "Antenna Gain and Bandwidth Enhancement Using Frequency Selective Surface with Double Rectangular Ring Elements," *International Symposium on Antenna, Propagation and EM Theory*, pp. 271- 274, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[5] Ricky Chair, K. F. Lee, and K. M. Luk, "Bandwidth and Cross-Polarization Characteristics of Quarter-Wave Shorted Patch Antenna," *Microwave and Optical Technology Letters*, vol. 22, no. 2, no. 101- 103, 1999. [CrossRef] [Google Scholar] [Publisher Link]

[6] R. B. Waterhouse, "Broadband Stacked Shorted Patch," *Electronics Letters*, vol. 35, no. 2, pp. 98- 100, 1999. [CrossRef] [Publisher Link]

[7] Ka-Lam Lau, Kwai-Man Luk, and Kai-Fong Lee, "Design of a Circularly-Polarized Vertical Patch Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 3, pp. 1332- 1335, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[8] David M. Pozar, and Daniel H. Schaubert, *Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays*, Wiley-IEEE Press, 1995. [Google Scholar] [Publisher Link]

[9] L. Lolit Kumar Singh, Bhaskar Gupta, and Partha P. Sarkar, "T-slot Broadband Rectangular Patch Antenna," *International Journal of Electronic and Electrical Engineering*, vol. 4, no. 1, pp. 43- 47, 2011. [Publisher Link]

[10] Mohammad Aneesh et al., "Analysis of S-Shape Microstrip Patch Antenna for Bluetooth Applications," *International Journal of Scientific and Research Publications*, vol. 3, no. 11, pp. 1-4, 2013. [Google Scholar] [Publisher Link]

[11] S. N Mulgi et al., "Design and Development of Wideband Gap-Coupled Slot Rectangular Microstrip Array Antenna," *Indian Journal of Radio and Space Physics*, vol. 37, pp. 291- 295, 2008. [Google Scholar] [Publisher Link]

[12] Anshika Khanna, and D. K. Srivastava, "Modified Edged Microstrip Square Patch Antenna with Square Fractal Slots For Bluetooth Applications," *International Journal of Engineering Research & Technology (IJERT*, vol. 3, no. 6, pp. 320- 323, 2014. [Google Scholar] [Publisher Link]

[13] Tyagi Santosh, and Kirti Vyas, "Bandwidth Enhancement Using Slotted U-Shape Microstrip Antenna With Pbg Ground," *International Journal of Advanced Technology and Engineering Research*, vol. 3, no. 1, pp. 23- 27, 2013. [Google Scholar]

[14] Ashok Kumar Kajla, Sheeba Khan, and Rhishika Kushwaha, "Microstrip Patch Antenna Using Crown And Sierpinski Fractal Slot," *International Journal of Advance Research in Science and Engineering*, vol. 2, no. 10, pp. 66- 75, 2013. [Google Scholar] [Publisher Link]

[15] Hemant Kumar Gupta et al., "Slotted Circular Microstrip Patch Antenna Designs for Multiband Application in Wireless Communication," *International Journal of Engineering and Technology*, vol. 1, no. 3, pp. 158- 167, 2012. [Google Scholar] [Publisher Link]

[16] S. Elajoumi et al., "Bandwidth Enhancement of Compact Microstrip Rectangular Antennas for UWB Applications," *Telkomnika Telecommunication, Computing, Electronics and Control*, vol. 17, no. 3, pp. 1559 – 1568, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[17] Kalyan Mondal, and Partha Pratim Sarkar, "M-Shaped Broadband Microstrip Patch Antenna with Modified Ground Plane," *Microwave and Optical Technology Letters*, vol. 57, no. 6, pp. 1308 –1312, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[18] Dawit Fitsum, Dilip Mali, and Mohammed Ismail, "Bandwidth Enhancement of Rectangular Microstrip Patch Antenna using Defected Ground Structure," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 3, no. 2, pp. 428 – 434, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[19] Anshika Khanna, Dinesh Kumar Srivastava, and Jai Prakash Saini, "Bandwidth Enhancement of Modified Square Fractal Microstrip Patch Antenna using Gap-Coupling," *Engineering Science and Technology, an International Journal*, vol. 18, no. 2, pp. 286 – 293, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[20] Ehab K. I. Hamad, and Gehad Nady, "Bandwidth Extension of Ultra-wideband Microstrip Antenna using Metamaterial Double-side Planar Periodic Geometry," *Radio Engineering*, vol. 28, no. 1, pp. 25 – 32, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[21] Ahmad Al-Ahmadi, and Yahya S. H. Khraisat, "Bandwidth Enhancement of Microstrip Patch Antenna," *Applied Physics Research*, vol. 11, no. 1, pp. 35- 40, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[22] Yahya S. H. Khraisat, "Increasing Microstrip Patch Antenna Bandwidth by Inserting Ground Slots," *Journal of Electromagnetic Analysis and Applications*, vol. 10, no. 1, pp. 1-11, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[23] Ali Hanafiah Rambe, Mutiara Widasari Sitopu, and Suherman Suherman, "Bandwidth Enhancement of Rectangular Patch Microstrip Antenna Using Left Handed Metamaterial at 2.4 GHz," *IOP Conference Series: Materials Science and Engineering*, vol. 420, pp. 1- 5, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[24] Felipe Ferreira de Araújo et al., "Bandwidth Enhancement of Microstrip Patch Antenna Using Metasurface," *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, vol. 20, no. 1, pp. 105-117, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[25] Clément Mbinack et al., "Inset-fed Rectangular Microstrip Patch Antenna Bandwidth Enhancement," *Microwave and Optical Technology Letters*, vol. 61, no. 2, pp. 562-567, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[26] Harshit Srivastava et al., "Bandwidth and Gain Enhancement of Rectangular Microstrip Patch Antenna (RMPA) Using Slotted Array Technique," *Wireless Personal Communications*, vol. 114, pp. 699 – 709, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[27] Dheeraj Tripathi, D. K. Srivastava, and Ramesh Kumar Verma, "Bandwidth Enhancement of Slotted Rectangular Wideband Microstrip Antenna for the Application of WLAN/WiMAX," *Wireless Personal Communications*, vol. 119, pp. 1193-1207, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[28] M. Ramkumar Prabhu, A. Rajalingam, and J. Latha, "Bandwidth Enhancement by Corner Truncation in Rectangular Patch Antenna," *American International Journal of Multidisciplinary Scientific Research*, vol. 1, no. 1, pp. 1-6, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[29] Khanda Anum et al., "Bandwidth Enhancement of A Microstrip Patch Antenna for Ultra-Wideband Applications," *AIP Conference Proceedings*, vol. 1952, no. 1, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[30] Soumen Banerjee, and Susanta Kumar Parui, "Bandwidth Improvement of Substrate Integrated Waveguide Cavity-Backed Slot Antenna with Dielectric Resonators," *Microsystem Technology*, vol. 26, pp. 1359 – 1368, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[31] G. Viswanadh Raviteja et al., "Gain and Bandwidth Considerations for Microstrip Patch Antenna Employing U and Quad L shaped Slots with DGS and Parasitic Elements for WiMax / WiFi Applications," *European Journal of Engineering Research and Science*, vol. 5, no. 3, pp. 327- 330, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[32] Ali Faraj Darweesh, and G. O. Yetkin, "Enhancement of the Gain and the Bandwidth of a UWB Microstrip Patch Antenna Using Metamaterials," *International Journal of Engineering & Technology*, vol. 7, no. 3.14, pp. 380-385, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[33] Dian Rusdiyanto et al., "Bandwidth and Gain Enhancement of Microstrip Antenna using Defected Ground Structure and Horizontal Patch Gap," *SINERGI*, vol. 25, pp. 153-158, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[34] M. V. Yadav, and S. Baudha, "A Compact Mace Shaped Ground Plane Modified Circular Patch Antenna for Ultra-Wideband Applications," *Telecommunications and Radio Engineering*, vol. 79, no. 5, pp. 383-397, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[35] Boualem Hammache et al., "Compact Stepped Slot Antenna for Ultra-Wideband Applications," *International Journal of Microwave and Wireless Technologies*, vol. 14, no. 5, pp. 609-615, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[36] Boualem Hammache et al., "Compact Ultra-Wideband Slot Antenna with Three Notched Band- Characteristics," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 30, no. 5, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[37] Tanmoy Sarkar et al., "A New Insightful Exploration into a Low Profile Ultra-Wide-Band (UWB) Microstrip Antenna for DS-UWB Applications," *Journal of Electromagnetic Waves and Applications*, vol. 35, no. 15, pp. 2001-2019, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[38] Dattatreya Gopi, Appala Raju Vadaboyina, and J. R. K. Kumar Dabbakuti, "DGS Based Monopole Circular Shaped Patch Antenna for UWB Applications," *SN Applied Sciences*, vol. 3, no. 198, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[39] Abbas Abbas et al., "A Rectangular Notch-Band UWB Antenna with Controllable Notched Bandwidth and Centre Frequency," *Sensors*, vol. 20, no. 3, 2020. [CrossRef] [Google Scholar] [Publisher Link]