

Original Article

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

M. Firoz Ahmed<sup>1</sup>, Abu Zafor Md. Touhidul Islam<sup>2</sup> and M. Hasnat Kabir<sup>3</sup>

<sup>1,3</sup> Department of Information and Communication Engineering, University of Rajshahi, Rajshahi-6205, Bangladesh

<sup>2</sup> Department of Electrical and Electronic Engineering, University of Rajshahi, Rajshahi-6205, Bangladesh

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**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).

## I. 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 surface [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 application [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 indicating 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-wideband (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.

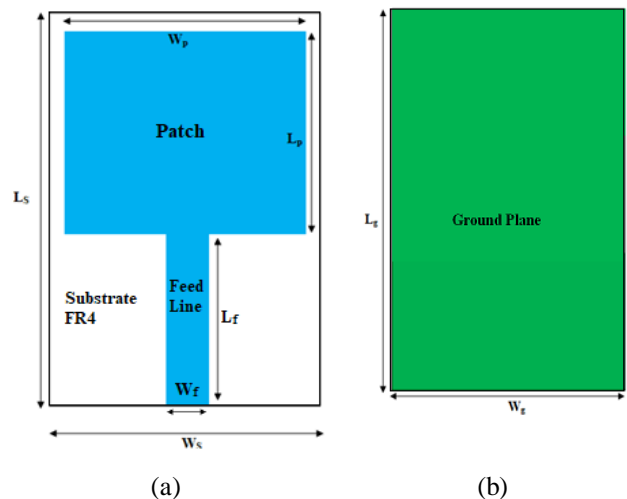
Two steps are used to design a rectangular patch microstrip antenna for UWB applications in this paper. A conventional antenna with the full ground plane is designed in the first step. In the second step, a combination of partial ground with a single rectangular slot inserted on the upper edge of the 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.

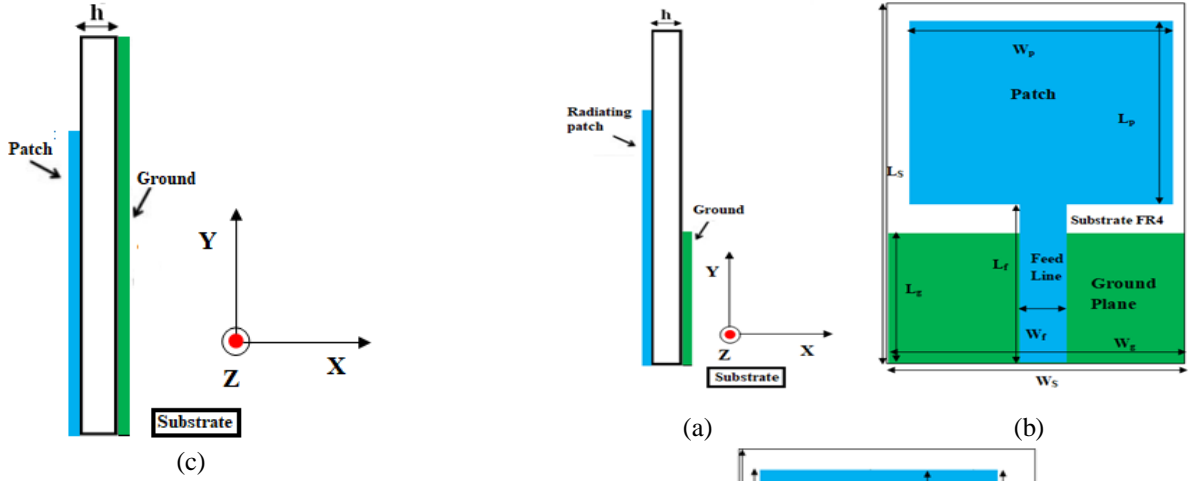
Partial ground reduces the amount of energy stored in the substrates. The decrease in quality factors (Q) is caused by a decrease in energy storage in the substrates. The bandwidth increases as the Q factor decreases. Back radiation is a result of a partial ground plane. Hence, there will be a greater 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.

## II. PROPOSED ANTENNA DESIGN

### A. 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 FR4 substrate with a dielectric constant ( $\epsilon_r$ ) of 4.4, a thickness (h) of 0.8mm, and the loss tangent ( $\tan\delta$ ) is 0.02. A microstrip feed line is used to excite the patch with a characteristic impedance of 50 $\Omega$ . The various parameters of a conventional rectangular patch antenna are shown in Table I.





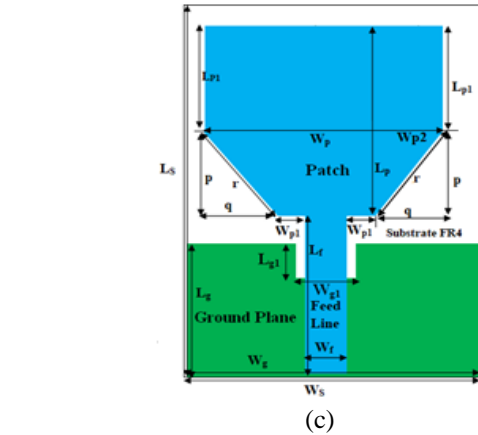
**Fig. 1: Geometry of the conventional rectangular patch microstrip antenna (a) Top view (b) Bottom view (c) Side view**

**TABLE I: 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, $\epsilon_r$	4.4
Microstrip feedline width, $W_f$	2 mm	Operating frequency	6.85G Hz
Microstrip feedline length, $L_f$	15 mm	Dielectric loss tangent	0.02

**B. 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.



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

**TABLE II: 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

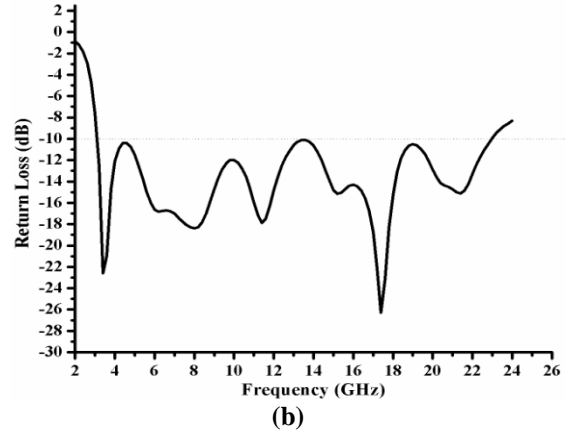
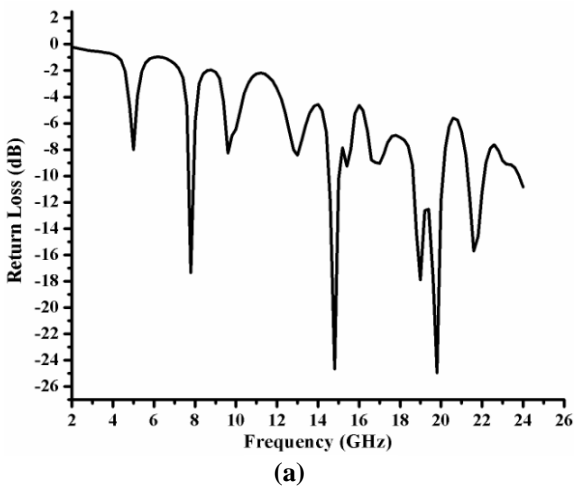
**III. SIMULATION RESULTS AND DISCUSSION**

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.

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

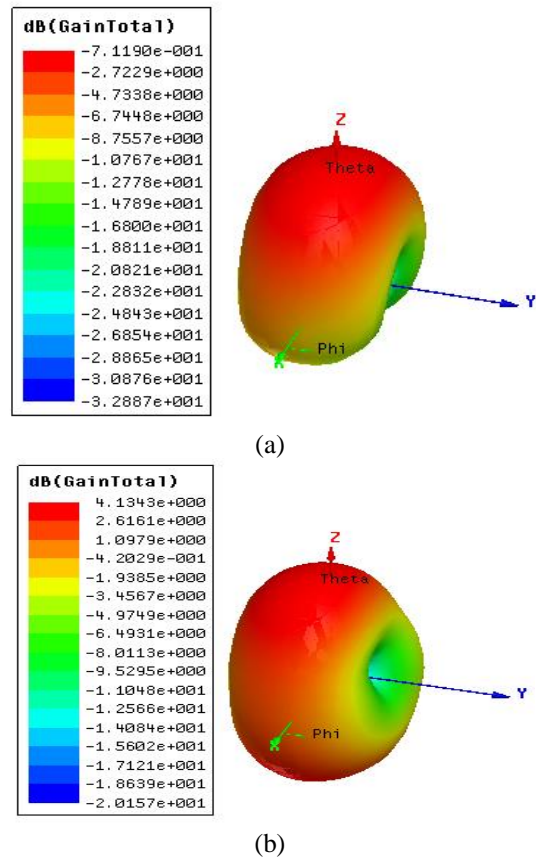
must be less than or equal to -10 dB for a specific frequency band. The return loss versus frequency plot of the conventional antenna with a full ground plane is shown in Fig. 3 (a). The antenna exhibits multiband behavior and operates on four resonant frequencies: 7.80 GHz, 14.8 GHz, 19.80 GHz, and 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 to 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.



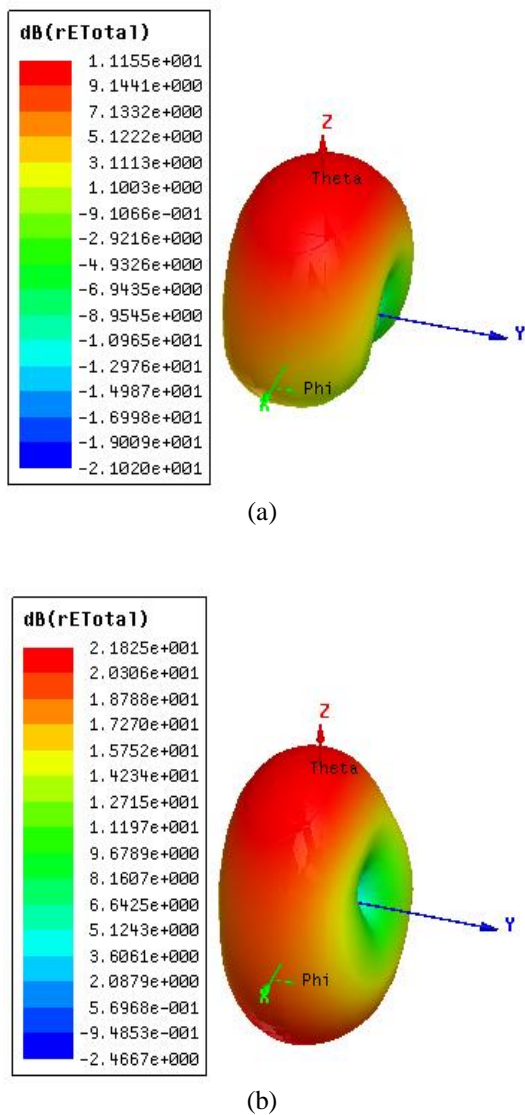
**Fig. 3: Return loss versus frequency plot of (a) the conventional antenna with full ground plane and (b) the proposed antenna**

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.



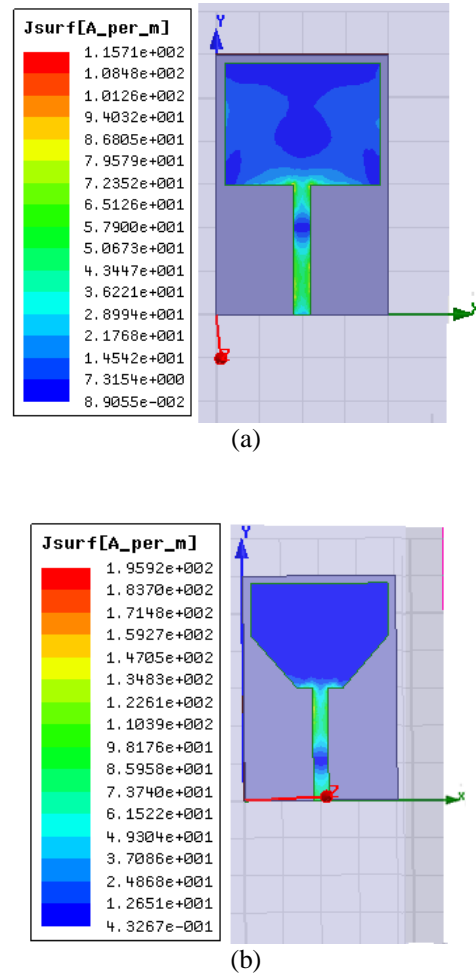
**Fig. 4: Simulated 3D gain at 6.85GHz (a) conventional antenna (b) proposed antenna**

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.



**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.



**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 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 III: Comparisons of the preceding and present designed rectangular microstrip patch antennas**

Reference No's	Antenna Size, (mm <sup>3</sup> )	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

#### IV. CONCLUSIONS

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).

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