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Design of a compact patch antenna with bandwidth and efficiency improvement for UWB applications

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Abstract This article demonstrates a hybrid technique (HT) based compact rectangular patch antenna for ultra-wideband (UWB) (3.1-10.6 GHz) applications. The aim of this work is to enhance the bandwidth and efficiency of the antenna. The HT is formed by combining a slotted patch with a defected ground structure (DGS). A low-cost FR4_epoxy dielectric substrate material is used to design the proposed antenna. It has a dielectric constant of 4.4, a thickness of 0.8 mm, and a loss tangent of 0.02. The antenna is designed to resonate at 6.85 GHz. The overall size of the proposed antenna is 30 mm × 20 mm × 0.8 mm. A 50 Ω microstrip feedline is used to excite the patch. It is simulated using high-frequency structure simulator (HFSS) software and the results are compared with the basic antenna with DGS. The outcomes of the simulation reveal that the suggested antenna and the antenna with DGS achieved a bandwidth of 19.7 GHz and 2.53 GHz with an efficiency of 95.779% and 92.296%, respectively. The recommended antenna has boosted in bandwidth and efficiency by 17.17 GHz (137.24%) and 3.483%, respectively as compared to the basic antenna with DGS.

Keywords: rectangular patch, UWB, HT, FR-4 substrate, HFSS, bandwidth, efficiency

1. Introduction

Ultra-wideband (UWB) antenna utilization is regulated by some rules established forth by the Federal Communication Commission (FCC). The UWB devices have an antenna impedance bandwidth ranging from 3.1 GHz to 10.6 GHz. It can be used with any communication that uses at least 500 MHz of the available spectrum (Liang 2006). The UWB technology is one of the most potential wireless technologies available today because it ensures high data rate transmissions, low complexity, minimal interference, and simple connection in a wide range of devices such as laptops, digital cameras, and high-definition TVs. Moreover, it permits the industry to offer end users higher-quality facilities. In portable devices, high-performance printed circuit board antennas are necessary (Bao and Ammann 2007).

Microstrip patch antennas (MPAs) are considered to be a crucial element for these uses because of their benefits such as low profile, low cost, ease of integration with microwave integrated circuits (MIC), and lightweight. It consists of a dielectric material sandwiched between two metal layers. The layer with the largest surface area is the ground plane, which is the bottom layer. The upper layer is referred to as a patch (Satyanarayana and Shankaraiah 2018). Patch can be made in a variety of forms like diamond, hexagonal, square, elliptical, circular, triangular, and bowties (Patil 2012). However, the most typical antenna geometry that has been thoroughly studied is the rectangular patch (Chattopadhyay et al 2007). The low gain, poor efficiency and limited bandwidth are the main constraints of patch antenna.

Several strategies were developed to overcome these limitations such as the use of inserted slots, corrugation structures, shorting pins, meandering slots, increasing the substrate thickness and dielectric substrate permittivity, double substrate methodology (Upadhyay and Dwivedi 2014), shorter patches (Rama and Vakula 2014), slotted ground (Satam and Nema 2015) slot-loading (Choukiker et al 2013), L-shaped spur lines with H- or I-shaped defective ground structures (DGS) (Sharma and Singh 2008), shorter patches (Chandrappa et al 2014). Microstrip patch antennas (Anum et al 2018; Darweesh and Yetkin 2018) were constructed to increase bandwidth and gain for ultra-wideband applications by using slotting feedline, a curved slot in the patch, a shift in patch shape, and metamaterials. In order to enhance the bandwidth, a slotted partial ground and a coaxial feed method were used to design a compact rectangular patch antenna for ultra-wideband applications (Thorat et al 2020; Malik 2020). However, multiple studies are currently being carried out in the area of microstrip patch antennas. Antenna bandwidth expansion is the main focus of the majority of these investigations.

Previously, we proposed a rectangular patch antenna for UWB applications with increased gain and bandwidth and compared the results with the conventional antenna without defected ground structure (DGS). A conventional antenna without DGS had been considered as a basic antenna. The current work is a continuation of previous study.

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In this paper, a compact rectangular patch antenna for UWB applications using hybrid technique is proposed. The main goal of this work is to increase the bandwidth and efficiency of the antenna. The antenna is designed in two stages. A simple patch antenna with a defected ground structure (DGS) is developed in the initial stage. This one is treated as a basic antenna throughout this article. In the second stage, the antenna is constructed using hybrid technique (HT). A basic patch antenna with a DGS and a slotted patch are combined to form HT. The suggested antenna has been evaluated and simulated using a high-frequency structure simulator (HFSS).

The paper is organized as follows: The literature review is presented in Section 2. The design methodology is explained in Section 3. Section 4 introduces the antenna construction. Section 5 demonstrates the simulation's results and discussion. In Section 6, a comparison of the suggested work with recently published works is presented. Finally, the conclusion is described in Section 7.

2. Literature Review

Different parameters for microstrip patch antennas were characterized by a variety of studies. We have described a few recent and current techniques for improving the bandwidth and efficiency of microstrip patch antennas.

A mace-shaped ground plane, split-ring resonators (SRR), and faulty ground structure were used to create circular microstrip patch antennas that would improve the bandwidth for ultra-wideband systems (Yadav and Baudha 2020; Gopi et al 2021; Subitha et al 2021). A partial ground plane (PGP) with grooves, R-slots, T-shaped slots, and L-shaped slots were employed to raise the bandwidth of tiny slit antennas for ultra-wideband usage (Baudha et al 2020; Hammache et al 2022; Hammache et al 2020). Reconfigured patches, compressed ground surfaces, and imperfect ground layers were applied to enhance the bandwidth of planar antennas (Baudha et al 2020; Baudha et al 2019; Singh et al 2020).

Defected ground structure (DGS)-based microstrip patch antennas were introduced in (Belekar et al 2017), to improve bandwidth, efficiency, and diminish return loss. It was reported that the antenna had a 147.8 MHz bandwidth, 15.8 efficiency, and a -33 dB return loss. The bandwidth and efficiency of a microstrip antenna were enhanced by adding a slot to several patch configurations (Hakeem and Nahas 2021). The bandwidth, efficiency, and compactness of the antenna were improved by creating a rectangular microstrip patch antenna with a metamaterial structure (Darboe et al 2019). It was able to achieve an efficiency of 0.02129 dB with a bandwidth of 3161 MHz. By incorporating various configurations (rectangular and U) of single and double slots into the patch, as well as inset feed and coaxial feed methods, a basic rectangular patch antenna was developed to boost bandwidth and efficiency (Nahas 2019).

A microstrip patch antenna's design and modeling for enhancing signal reception in wireless communication systems were described (Okoro and Oborkhale 2021). This antenna attained an efficiency of 94.2%. A simplified, fastened microstrip square patch antenna for usage in 5G and future wireless communication systems was demonstrated (Subitha et al 2022). The devised antenna had a bandwidth of 226.2 MHz and an efficiency of 96.6%. Ultra-wideband monopole antennas with a higher bandwidth were constructed using metamaterial and defected ground structure (DGS) methodologies. They obtained bandwidths of 11.02 GHz and 7.5 GHz with 97% and 95% efficiency, respectively (Al-Bawri et al 2020; Vijayalakshmi and Murugesan 2019).

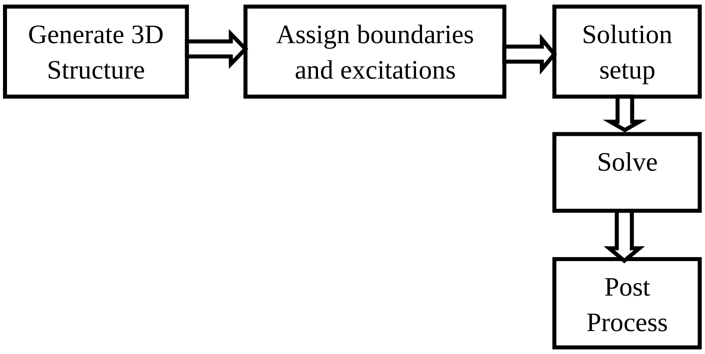
3. Design Methodology

The primary goal of the study is to design a tiny rectangular microstrip patch antenna with enhanced bandwidth and efficiency for use in UWB bands. A compact microstrip patch antenna can be made by choosing the simulating software, design requirements, and parameter (dimension) estimates.

3.1. Choice of Simulation Software

A microstrip patch antenna can be constructed using a variety of software such as COMSOL, MATLAB, IE3D, MWO, SONNET, FEKO, ADS, HP MDS, CST MS, and HFSS etc (Odeyemi et al 2011; Patir 2015). However, the ANSYS HFSS (v.15) software is selected for design and simulation in this research work because it is based on the Finite Element Method (FEM) techniques (Felippa 2004). It is the most accurate, flexible, and appropriate software for simulating volumetric structures like the microstrip patch antenna. Parameters like return loss, VSWR, resonant frequency, gain, directivity, radiation pattern, efficiency and fields can be determined by using Ansoft HFSS (High Frequency Structure Simulator). There are six crucial steps in creating and solving a proper HFSS simulation. These are:

1. Create model/geometry
2. Assign boundaries
3. Assign excitations
4. Set up the solution
5. Solve
6. Post-process the results



The parameters and pc environment for the simulated software are given in Tables 1 and 2, respectively.

Table 1 Simulation parameters.

No.	Parameters	Values
1	Frequency band used	UWB band
2	Solution frequency (operating frequency)	6.85 GHz
3	Frequency sweep	Discrete
4	Boundary conditions	Perfect E
5	Port Excitation	Lumped port (50+j0) Ohm
6	Solution types	Driven
7	Adaptive solution	Maximum Delta S (0.02)
8	Substrate dielectric material	FR-4_epoxy (4.4)
9	Substrate (X, Y, Z)	0.8 mm, 20 mm, 30 mm
10	Material used in patch and ground plane	Copper
11	Patch (Y, Z)	18 mm, 14 mm
12	Ground plane (Y, Z)	20 mm, 14 mm
13	Radiation box	Air
14	Microstrip feedline position (X, Y, Z)	0.8 mm, 9 mm, 0 mm

Table 2 PC environment.

No.	Parameters	Values
1	Operating system	Windows 10
2	Processor	Intel Core i7
3	RAM	20 GB

3.2. Design procedure

The following procedures are required to design and simulate a compact rectangular microstrip patch antenna with microstrip feedline:

3.2.1. Determining the operating frequency referred to as the resonant frequency (f_0).
3.2.2. Choose an appropriate dielectric substrate material.
3.2.3. Select the substrate's height (h).
3.2.4. Choose the proper patch sizes (width and length).
3.2.5. Choose a feeding strategy.
3.2.6. Find the feed position.

3.3. Design requirements

Consider the design requirements of the antenna based on its desired application as the first stage before constructing a microstrip patch antenna. When developing a rectangular microstrip patch antenna for a range of wireless applications, three key design requirements must be taken into consideration. These are:

3.3.1. Frequency of operation (f_0):

The proposed antenna is designed for 3.1 to 10.6 GHz UWB-band applications. Therefore, the antenna design is chosen for an operating frequency (f_0) of 6.85 GHz in the UWB-band range of 3.1 - 10.6 GHz.

3.3.2. Dielectric material (ε_r):

The selection of a dielectric material with the proper dielectric constant (ε_r) has a significant impact on the performance of an antenna. It has a major effect on gain, bandwidth, radiation loss, and operating frequency change (Hanumante and Roy 2013). The dielectric constant is another factor that affects the fringing field, which is the primary cause of radiation in microstrip patch antennas. The smaller the value of ε_r, the wider the fringes, the diminish the conductor loss, the better the radiation and the higher the bandwidth and efficiency. The higher value of ε_r will decline the patch size of the antenna. The substrate material selected for the suggested antenna design is FR4, which has a loss tangent (tan δ) of 0.02 and a dielectric constant (ε_r) of 4.4. For a microstrip patch antenna, the dielectric constant and the dielectric loss tangent range from 2.2 to 12 and 0.001 to 0.06 respectively.

3.3.3. Height of dielectric substrate (h):

The height of the substrate (h) has an impact on the control of the bandwidth and surface waves (Singh and Tripathi 2011). The dielectric height for our designed antenna is 0.8 mm. Increasing the height of the dielectric substrate (h)causes an increase in surface wave power, spurious feed radiation, a decrease in radiation efficiency, and an increase in antenna size and bandwidth. It also impacts inductive impedance.

3.4. Design of rectangular microstrip patch antenna

The basic equations required to perform this procedure are used to calculate the dimensions of the proposed microstrip-fed rectangular microstrip patch antenna (RMPA). The transmission line model is employed to determine the design parameters of the antenna because it offers a simple, realistic, and clear understanding of the RMPA design.

3.4.1. Calculations of design parameters

The following process and parameter equations are used to develop a single-element, single-band rectangular microstrip patch antenna:

Step-1: Calculation of the patch width (W_p):

The width (W_p) of the patch for an efficient radiator is calculated using the transmission line model equation as follows (Balanis 2005):

$$W_p = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

Where, c = light speed in vacuum

f_0 = resonant frequency

Step-2: Calculation of effective dielectric constant (ε_{reff}):

The effective dielectric constant is determined from the height and width of the antenna and the dielectric constant of the substrate. It is always less than the substrate's dielectric constant due to the fringe effects. It is calculated using the given equation (Balanis 2005):

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W_p}]^{-1/2}$$

Where, $\varepsilon_{\text{reff}}$ = Effective dielectric constant

ε_r = Dielectric constant of the substrate

h = Height of the dielectric substrate

W_p = Width of the patch

Step-3: Calculation of effective length (L_{eff}) of patch:

The effective length is calculated using the following formula (Balanis 2005) for a given resonance frequency f_0:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}}$$

Step-4: Computing of the patch length extension (ΔL_p):

The term "length extension" refers to the extra length created at the patch's end by the fringing field along its width. It is calculated using the given formula (Balanis 2005):

$$\Delta L_p = 0.412h\frac{(\varepsilon_{\text{reff}} + 0.3)(\frac{W_p}{h} + 0.264)}{(\varepsilon_{\text{reff}} - 0.258)(\frac{W_p}{h} + 0.8)}$$

Step-5: Estimating the actual length of the patch (L_p):

The difference between the patch's effective length and its doubled length extension is called the patch's actual length. Mathematically, it is expressed as (Balanis 2005):

$$L_p = L_{eff} - 2\Delta L_p$$

More power is emitted when the patch width is higher, which results in less resonance resistance, wider bandwidth, and improve radiation efficiency. The patch width (W_p) can be chosen to be greater than the patch length with the appropriate proportions of excitation. It has been suggested that $1 < {W_p}/{L_p} < 2$.

Step-6: Determining the dimensions of the ground plane

The transmission line model can only be used with infinite ground planes. But according to (Balanis 2005), a finite ground plane must be bigger than the patch dimensions by roughly six times the substrate thickness all around the edges for practical reasons. Therefore, the length (L_g) and width (W_g) of the ground plane are usually calculated using the following formulas:

$$L_g = L_p + 6h$$
$$W_g = W_p + 6h$$

Where, L_p and W_p are the length and the width of the patch antenna

Step-7: Feeding technique and feed point location

Feed is one of the components required to design an antenna. It is used to excite the patch (radiator) by direct or indirect contact. The most popular feeds for microstrip antennas such as proximity coupling, aperture coupling, and microstrip line feed. The suggested antenna is designed using a microstrip line feed because it is easier to model and match by adjusting the inset location. The impedance match will depend on where the feed point is placed on the patch. Enhanced impedance matching results in improved performance, including wider bandwidth and lower return loss. The following equation is used to determine the feed point locations ($\mathrm{Y_f}, \mathrm{Z_f}$) to match 50 Ω impedance since the antenna is designed on the YZ plane:

Along the patch width:

$$Y_f = \frac{W_p}{2}$$

Along the patch length:

$$Z_f = Z_0 - \Delta L_p$$

Where, $Z_0 = \frac{L_p}{\pi} cos^{-1}\sqrt{\frac{50}{Z_{in}}}$

Where, $Z_{in} = 90 * \frac{\varepsilon_r{}^2}{\varepsilon_r - 1}(\frac{L_p}{W_p})^2$ Ω = Input impedance of the patch.

L_p = Length of the patch.

W_p = Width of the patch.

ε_r = Dielectric constant of the patch.

These formulas give an estimated Y and Z coordinate for the feed point. The precise feed point location can be determined by an iterative testing procedure for better impedance matching.

3.5. Antenna performance parameters

3.5.1. Return loss (RL)

The quantity of mismatch is indicated by a return. It is the ratio between the power reflected by the antenna and the power supplied to the antenna through the transmission line and expressed in dB. The return loss is calculated using the formula below (Balanis 2005):

$$RL = 20log\left|\rho\right|$$

Where, |ρ| represents the magnitude of the reflection coefficient and this value is always below 1. The mathematical expression is:

$$\left|\rho\right| = \frac{Z_{in} - Z_c}{Z_{in} + Z_c}$$

Where, $Z_{in} = 90 * \frac{\varepsilon_r{}^2}{\varepsilon_r - 1}(\frac{L_p}{W_p})^2$ Ω = Input impedance of the patch

Z_c = Characteristics impedance of the transmission line

3.5.2. Bandwidth (BW):

An antenna's bandwidth is described as "the range of frequencies within which the performance of the antenna, with regard to specific parameters, conforms to a particular standard" (Milligan 1985; Mohammed et al 2015). A square or rectangular microstrip patch antenna's bandwidth is determined using the following formula in percentage terms (Balanis 2005).

$$BW = 3.77\left[\frac{(\varepsilon_r - 1)}{{\varepsilon_r}^2}\right]\left[\frac{W_p}{L_p}\right]\left(\frac{hf_0}{c}\right) \times 100\%$$

3.5.3. Radiation pattern

A microstrip antenna is essentially a broadside radiator with relatively wide beam width and low gain properties. The equations for the E and H plane radiation patterns are given by (Balanis 2005):

E-plane:

$$F(\varphi) = \left[\frac{sin\left\{\left(\frac{kh}{2}\right)cos\varphi\right\}}{\left(\frac{kh}{2}\right)cos\varphi}\right] \bullet cos\left[\left(\frac{kL_p}{2}\right)cos\varphi\right]$$

H-plane:

$$F(\theta) = \left[\frac{sin\left\{\left(\frac{kW_p}{2}\right)cos\theta\right\}}{\left(\frac{kW_p}{2}\right)cos\theta}\right] \bullet sin\theta$$

Where, $k = \text{free space wave number} = {}^{2\pi}/_{\lambda} = {}^{2\pi f_0}/_{c}$

h = height (thickness) of the substrate

W_p = Width of the patch

L_p = Length of the patch

3.5.4. Gain and directivity

The equation for approximating the directivity (D) of the rectangular microstrip antenna is given by (Balanis 2005):

$$D \cong 0.2\, W_p + 6.6 + 10log\left(\frac{1.6}{\sqrt{\varepsilon_r}}\right) dB$$

Where, ε_r = Dielectric constant of the substrate

W_p = Width of the patch

Gain (Balanis 2005):

$$G = \frac{4\pi f_0^2}{c^2} A_e$$

Where, A_e= Effective area of the rectangular patch antenna

f_0= resonant frequency

c = light speed in vacuum

3.5.5. Efficiency (Balanis 2005):

$$\eta = \frac{G}{D}$$

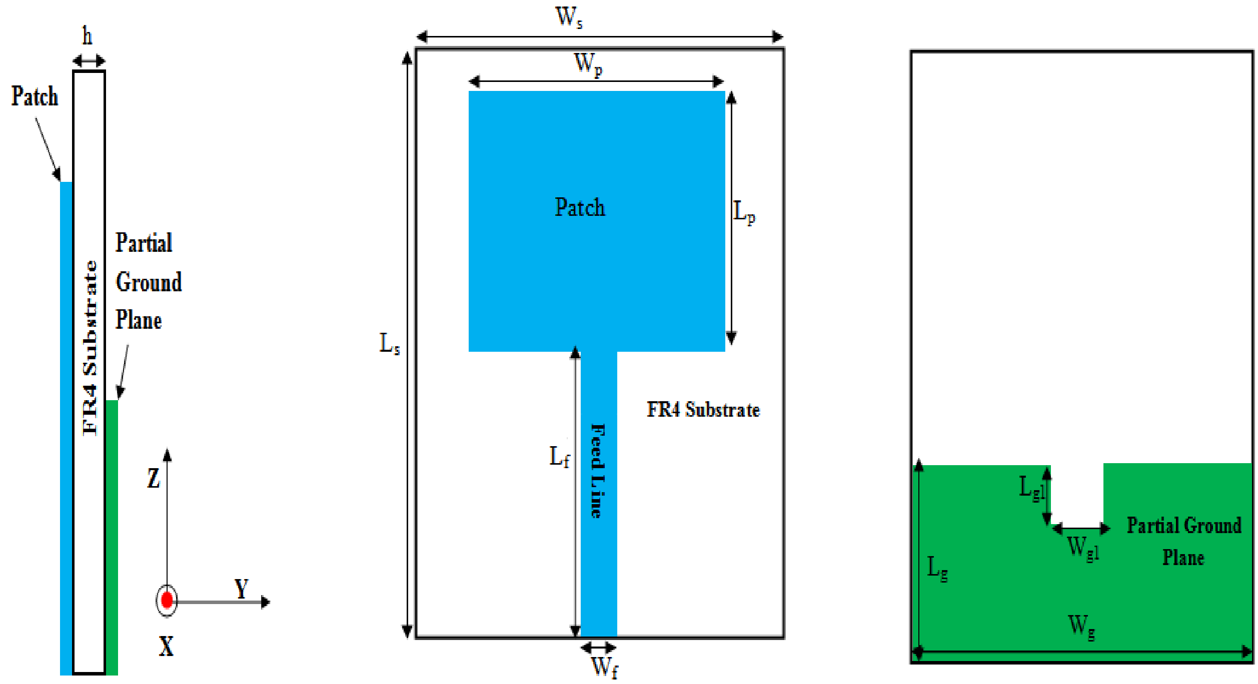
3.6. Effect of slot on size on antenna

The slot helps to reduce the size of the microstrip patch antenna. This will change the path of the current. Patch current changes when slots are carved into it. More current passes through the additional patch as opposed to the microstrip patch antenna without slots.

4. Antenna structure

4.1. Simple patch antenna with a defected ground structure

A basic microstrip antenna (BMA) with a defected ground structure (DGS) has initially been designed for comparative evaluation of the proposed antenna with slotted patch. BMA consists of a rectangular patch, DGS, FR4 substrate, and a single microstrip feedline, as shown in Figure 1. The patch and DGS are generally made of conducting material such as copper or gold. A microstrip feedline with a characteristic impedance of 50 ohms is used to fed the antenna. The antenna is designed on FR4-epoxy substrate material with a total dimension of 30 mm × 20 mm × 0.8 mm with a dielectric constant of 4.4 and a tangent loss of 0.02. Table 3 shows the dimensions of the basic microstrip patch antenna.



(a) (b) (c)

Figure 1 Basic patch antenna with defected ground structure (a) side view, (b) front view and (c) bottom view.

Table 3 Proper dimensions of the basic patch antenna with defected ground structure.

No.	Parameter (Symbol)	Value	Description
1	Ws	20 mm	Width of substrate
2	Ls	30 mm	Length of substrate
3	h	0.8 mm	Thickness of substrate
4	Wp	18 mm	Width of patch
5	Lp	14 mm	Length of patch
6	W_f	2 mm	Width of 50 Ω microstrip feedline
7	L_f	15 mm	Length of 50 Ω microstrip feedline
8	Wg	20 mm	Width of ground plane
9	Lg	14 mm	Length of partial ground plane
10	Wg1	2 mm	Width of defected ground plane
11	Lg1	3 mm	Length of defected ground plane
12	f_0	6.85 GHz	Operating frequency
13	ε_r	4.4	Dielectric constant

4.2. Hybrid patch antenna

A hybrid patch (HP) is made by combining right-angle triangular and rectangular slots. The bandwidth and efficiency of the antenna are increased by using HP. Also, HP is employed to decrease antenna size, VSWR, and return loss. The structure of the suggested antenna as depicted in Figure 2 has been validated by our previous study (Ahmed et al 2021). In our earlier work, we mainly focused on enhancing the gain and bandwidth of the rectangular patch antenna for UWB applications and compared the outcomes with the traditional antenna without defected ground structure (DGS). The present work is a continuation of previous research. In previous studies, the conventional antenna without DGS was regarded as a fundamental antenna; however, in the present work, the conventional antenna with DGS has been taken into consideration as a basic antenna. The dimensions and parameters of the patch are same in the earlier study and the current work. The goal of the present study is to increase the efficiency and bandwidth of a compact rectangular patch antenna for UWB uses and compares the findings with the antenna with DGS. The optimal specifications for the planned antenna are shown in Table 4. The parameters have been achieved through a series of HFSS optimizations.

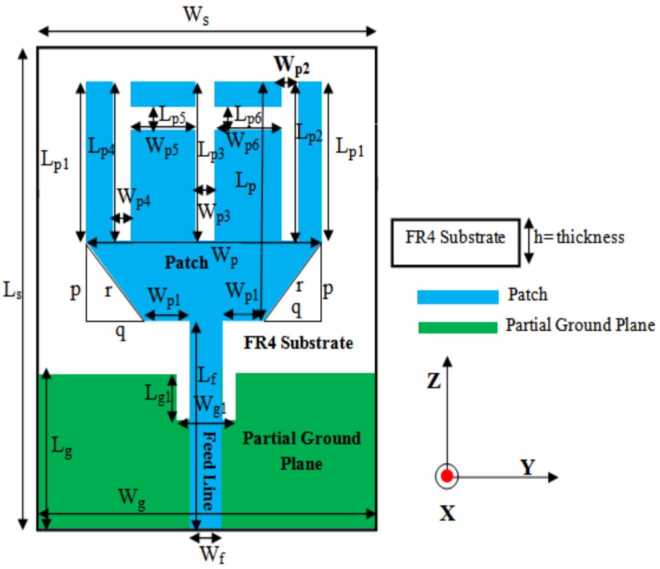


Figure 2 Proposed antenna structure.

Table 4 Optimized parameters of the proposed antenna.

No.	Parameter	Values (mm)	Description
1	Wp1	2	Width of patch rectangular slot 1
2	Lp1	8	Length of patch rectangular slot 1
3	Wp2 = Wp3 = Wp4	0.5	Width of patch rectangular slot 2,3& 4
4	Lp2 = Lp3 = Lp4	7	Length of patch rectangular slot 2,3& 4
5	Wp5 = Wp6	6.5	Width of patch rectangular slot 5& 6
6	Lp5 = Lp6	0.5	Length of patch rectangular slot 5& 6
7	p = q	6	Perpendicular and base of the right-angle triangle
8	r	8.48	Hypotenuse of the right-angle triangle

5. Simulation results and discussion

The antenna parameters such as return loss, bandwidth, radiation pattern, gain, directivity and efficiency for simple rectangular microstrip patch antenna (SRMPA) with a defected ground structure (DGS) and SRMPA with slotted patch also known as hybrid patch are presented in this section. High-frequency structure simulator (HFSS) software is used to simulate the antennas to obtain the results.

5.1. Return Loss (S_{11})

The amount of electrical power delivered from a feed point to an antenna is referred to as return loss (S_{11}). To effectively power transfer and good impedance matching, the S_{11} must always be negative. The S_{11} of the antenna must be less than or equal to -10 dB for a specific frequency band in order for it to function effectively in real-time applications. For instance, if an antenna has a S_{11} of -10 dB, it reflects 10% of the incident power. A lower S_{11} indicates that less power is being reflected from the antenna i.e. maximum power is delivered to the antenna which means better performance is achieved. In most cases, this is a desirable result. A higher S_{11} indicates that more power is returned from the antenna. This typically means an impedance mismatch between the feed point and the antenna. The return loss of the simulation results is shown in Figure 3. The reference antenna without a slotted patch i.e. the antenna with a defected ground structure (DGS) has resonance frequencies of 4.60 GHz and 18.25 GHz, with return losses of -16.11 dB and -16.36 dB, respectively, as shown by this graph. The performance of the patch antenna with DGS is good, with the smallest return loss of -16.36 dB at 18.25 GHz. On the other hand, the antenna with the slotted patch has multiple resonance frequencies, including 3.5 GHz, 6.8 GHz, 7.7 GHz, 11.7 GHz, and 17.7 GHz, with return losses of -20.94 dB, -23.49 dB, -28.35 dB, -19.58 dB, and -21.94 dB, respectively. The proposed antenna has a lower return loss of -28.35 dB at 7.7 GHz. It shows -11.99 dB reduced in return loss than the standard antenna with DGS. This return loss value of -28.35 dB is a good value since it is below (less than) the -10 dB minimum specified value for a suitable, realistic microstrip patch antenna design and indicates that the least amount of power (0.144%) is reflected from the antenna to the source input port.

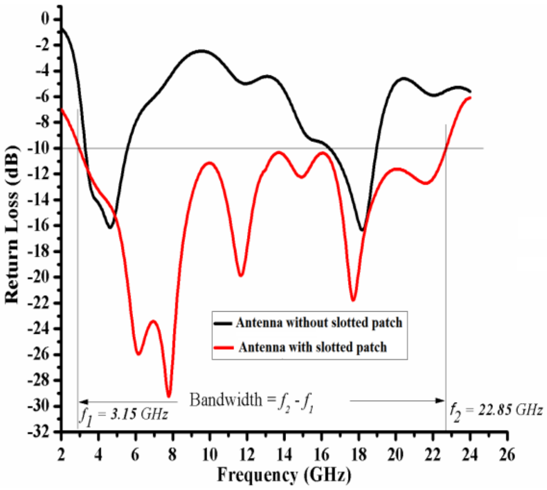


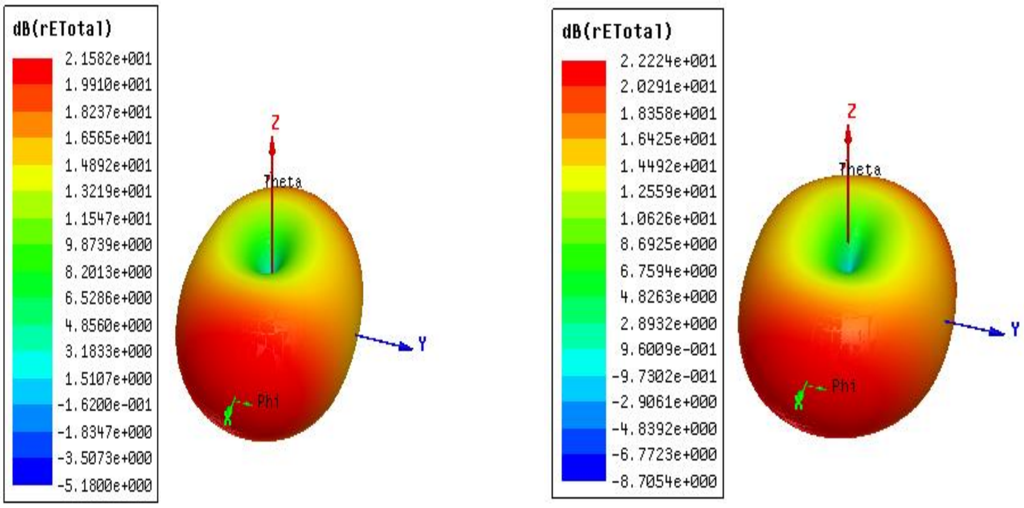
Figure 3 Return loss plot for antenna without and with slotted patch.

5.2. Bandwidth

The frequency range that an antenna can effectively transmit and receive power is known as its bandwidth. The return loss graph can be used to determine bandwidth. As can be seen from Figure 3, the antenna without slotted patch contains two bands (3.23 GHz to 5.55 GHz and 16.42 GHz to 18.95 GHz) with resonance frequencies of 4.60 GHz and 18.25 GHz. The second band has a bandwidth of 2.53 GHz (defined by -10 dB line) and the graph demonstrates that the antenna operates well at 18.25 GHz, where the return loss is - 16.36 dB. The proposed antenna has an impedance bandwidth of 19.7 GHz (3.15 GHz - 22.85 GHz), which is better than that presented in refs. (Anum et al 2018; Darweesh and Yetkin 2018; Thorat et al 2020; Malik 2020; Yadav and Baudha 2020; Gopi et al 2021; Subitha et al 2021; Baudha et al 2020; Hammache et al 2022; Hammache et al 2020; Baudha et al 2020; Baudha et al 2019; Singh et al 2020; Al-Bawri et al 2020; Vijayalakshmi and Murugesan 2019) and five (5) resonance frequencies of 3.5 GHz, 6.8 GHz, 7.7 GHz, 11.7 GHz, and 17.7 GHz. The graph also reveals that the planned antenna operates effectively at 7.7 GHz with a return loss of -28.35 dB. Therefore, the increase in bandwidth over the antenna without slotted patch (i.e. antenna with DGS) is 17.17 GHz.

5.3. Radiation Pattern

The radiation pattern is a key parameter in characterizing the performance of an antenna due to the role of an antenna is to radiate. Figure 4 (a) and (b) show a simulated 3D view of the far-field radiation patterns of the antenna with DGS and the proposed antenna based on FR4 substrate material at 6.85 GHz. The colors red, blue, yellow, and green signify the various radiation levels, from highest to lowest. Red indicates the greatest degree of radiation, while blue emerges for the smallest. The radiation pattern indicates omnidirectional radiation, with the reference patch antenna with DGS having a maximum power of 21.582 dB and the suggested antenna having a maximum power of 22.224 dB, indicating a significant advantage in ultra-wideband communication systems.

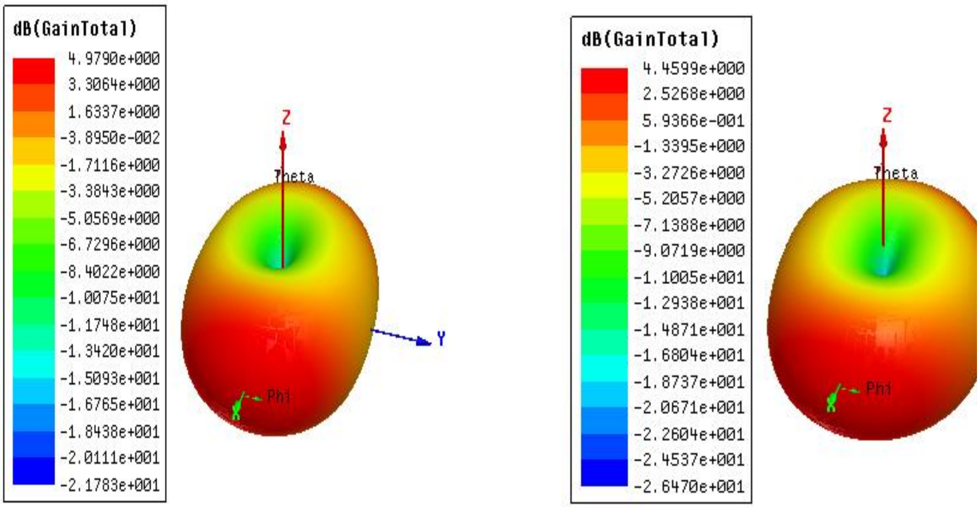


(a) (b)

Figure 4 Simulated 3D radiation pattern at 6.85GHz (a) Antenna with DGS (b) Proposed antenna.

5.4. Gain

Gain is a factor that affects an antenna's directionality. A low-gain antenna radiates at almost the same power in all directions, but a high-gain antenna mostly radiates in a few specific directions. The simulated results for 3D gain obtained from the antenna with DGS and the proposed antenna are shown in Figure 5 (a) and (b). This graph demonstrates that positive gain typically implies higher directivity but negative gain simply indicates less power is radiated in a specific direction. When an antenna is shown in three dimensions with a radiation pattern, it can sometimes be enough to represent the gain of the antenna since this also provides information regarding directivity. The antenna with DGS and the intended antenna have a peak gain of 4.9790 dB, and 4.4599 dB, respectively, at the operating frequency of 6.85 GHz. As a result, the gain of the antenna with DGS is approximately 1.12 times greater than the suggested antenna. Since the recommended antenna has a lower gain than the antenna with DGS, it radiates at almost the same power in all directions. On the other hand, the antenna with DGS emits primarily in a few limited directions because of its higher gain.

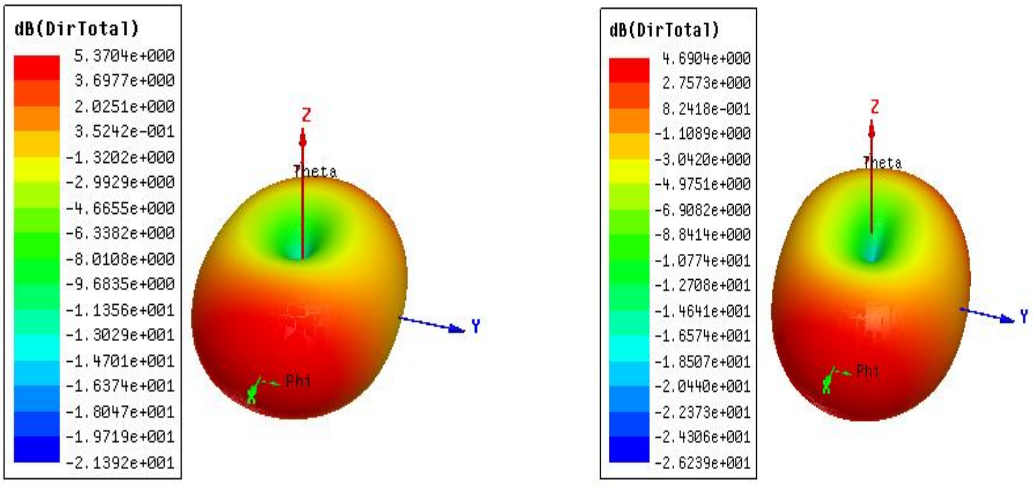


(a) (b)

Figure 5 Simulated 3D gain at 6.85GHz (a) Antenna with DGS (b) Proposed antenna.

5.5. Directivity

The amount of power that an antenna can radiate in a given direction is measured by its directivity. The directivity of the antenna with DGS and the planned antenna is depicted in Figure 6(a) and (b). Maximum directivities for the antenna with DGS and the suggested antenna at 6.85 GHz are 5.3704 dB and 4.6904 dB, respectively.



(a) (b)

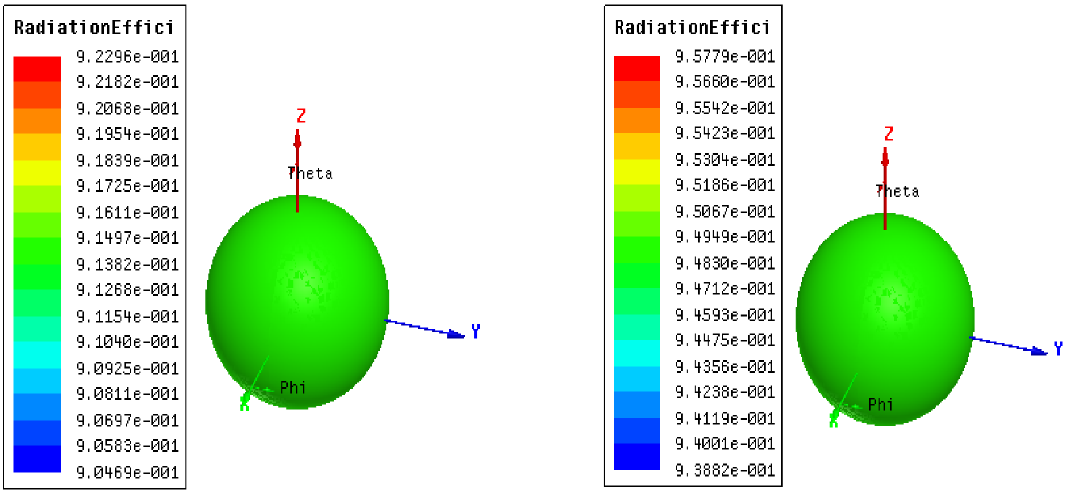
Figure 6 Simulated 3D directivity at 6.85GHz (a) Antenna with DGS (b) Proposed antenna.

5.6. Efficiency

The energy input-to-output ratio determines an antenna's efficiency. A high-efficiency antenna radiates most of the power applied at the antenna's input. A low-efficiency antenna loses the majority of its output power through internal losses or reflections caused by an impedance mismatch. The efficiency of the transmitting and receiving antennas is the same, and it is simpler to think about efficiency in terms of energy radiated versus energy supplied. It can be expressed as follows:

η = Energy radiated/ Energy input

In figure 7(a) and (b), the efficiency of the ordinary antenna with DGS and the proposed antenna are shown. The results of the simulation indicate that the planned antenna has an efficiency of 0.95779 (95.779%) which is dramatically higher than the efficiency of a normal antenna with DGS (0.92296) and superior to that demonstrated in Yadav and Baudha (2020), Baudha et al (2020), Hammache et al (2022), Baudha et al (2020), Baudha et al (2019) and Vijayalakshmi and Murugesan (2019). It clearly demonstrates that the recommended antenna efficiently radiates the large amount of power generated at an input. However, due to impedance mismatch, the majority of the power of the reference antenna with DGS is dissipated inwardly or reflected outwardly.



(a) (b)

Figure 7 Simulated 3D efficiency of an antenna at 6.85GHz (a) Antenna with DGS (b) Proposed antenna.

The bandwidth, bandwidth percentage, and efficiency of the planned antenna are compared to the ordinary antenna with DGS in Table 5. The table reveals that the bandwidths of the antenna with DGS and the recommended antenna are 2.53 GHz and 19.7 GHz, respectively, as well as their corresponding efficiency values of 92.296% and 95.779%. In comparison to the basic antenna with DGS, the proposed antenna has an increment in bandwidth and efficiency of 17.17 GHz and 3.483%, as seen in Table 5.

Table 5 Comparison between the suggested antenna and the antenna with DGS in terms of bandwidth, bandwidth percentage, and efficiency.

No.	Parameters	Antenna with DGS	Proposed Antenna	Improvement Factor
1	Bandwidth	2.53 GHz (18.95 GHz – 16.42 GHz)	19.7 GHz (3.15 GHz – 22.85 GHz)	17.17 GHz
2	Bandwidth percentage	14.03%	151.54%	137.24%
3	Efficiency	92.296%	95.779%	3.483%

Table 6 Comparison between our previous and present works.

No.	Parameters	Previous work		Present work		Improvement Factor	
		Antenna without DGS	Proposed antenna	Antenna with DGS	Proposed antenna	Previous work	Present work
1	Bandwidth	3.68 GHz (3.24 GHz – 6.92 GHz)	19.7 GHz (3.15 GHz – 22.85 GHz)	2.53 GHz (18.95 GHz – 16.42 GHz)	19.7 GHz (3.15 GHz – 22.85 GHz)	16.02 GHz	17.17 GHz
2	Bandwidth percentage	72.44 %	151.54 %	14.03%	151.54%	79.1%	137.24%

It is observed from table 6 that the current study has boosted by 58.14 % bandwidth over the earlier investigation.

6. Comparison of proposed work with some of the recent works

The recommended antenna and a few recently developed UWB antennas are compared in Table 7 for justifying their performances. From this table, it can be seen that a relatively similar efficiency has been achieved by the present antenna, however the bandwidth is found to be much higher as compared to the reference (Al-Bawri et al 2020). In both cases, the antenna size is almost the same. The suggested antenna is tiny in size and has a bandwidth of 19.7 GHz (3.15 GHz to 22.85 GHz), which is greater than that of the observed antennas.

Table 7 Comparisons of present work with previously published work.

Refs.	Antenna Size (mm³)	Operating Bandwidth (GHz)	Bandwidth (GHz)	Efficiency (%)	Methods
Darweesh and Yetkin (2018)	36 × 38 × 1.58	2.6 - 20	17.4 (approx.)	--------	Metamaterials
Thorat et al (2020)	50 × 38 × 1.6	2.8 - 18	15.2	---------	Slotted partial ground
Malik (2020)	40 × 50 × 0.8	16.2674 - 16.8307	0.5633	--------	Coaxial feed
Baudha et al (2020)	20 × 20 × 1.6	3.13 - 14.07	10.94	78	Reconfigured patches and truncated ground plane
Baudha et al (2019)	20 × 25 × 1.5	3.1 - 10.8	7.7	89	Modified patch and defective ground plane
Al-Bawri et al (2020)	22 × 14.5 × 1.6	3.08 - 14.1	11.02	97	Metamaterials
Vijayalakshmi and Murugesan (2019)	26.6 × 29.3 × 1.6	3.1 - 10.6	7.5	95	Defected ground structure
This work	30 × 20 × 0.8	3.15 - 22.85	19.7	95.779	Hybrid techniques (Slotted patch and defected ground plane)

7. Conclusions

In this article, a compact rectangular microstrip patch antenna for increasing the bandwidth and efficiency has been successfully designed and analyzed. The bandwidth and efficiency of the suggested antenna have been found to be boosted after employing hybrid methodologies. Simulated results from this study show that the proposed antenna has a 95.779% efficiency, and a 19.7 GHz bandwidth, while the basic antenna with DGS has a 92.296% efficiency and a 2.53 GHz bandwidth respectively. In comparison to a basic antenna with DGS, the bandwidth and efficiency have been improved by 17.17 GHz and 3.483%, respectively. Thus, the designed antenna is applicable to a wide range of wireless applications, including X band, C band, Ku band, S band, STM band, WiMAX, Wi-Fi, WLAN, radio astronomy, military communications, communications and sensors, positioning and monitoring, radar, and satellite communication applications. The fabrication of the suggested antenna as well as an assessment of the effectiveness of the practical and simulated antennas will be the main topics of future work. The proposed single-component structure would be integrated into an array on a single substrate, expanding the existing work. The gain, directivity, and efficiency of this design can be higher than its single analogue.

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Ethical considerations

Not applicable.

Conflict of Interest

The authors declare that they have no conflict of interest.

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