ORIGINAL PAPER

AN ULTRA-WIDEBAND PATCH ANTENNA FOR FUTURE INTERNET OF THINGS APPLICATIONS

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Abstract. *The Internet of Things (IoT) era is driving up demand for wireless connectivity, changing the tech sector. The creation of a compact, inexpensive, and effective antenna is crucial for supporting IoT devices. In this study, a hybrid strategy (HS)-based dense rectangular patch antenna for future Internet of Things applications (IoT) is demonstrated. A slotted patch and a partial ground with defected ground structure (DGS) are combined to create HS, leading to in a small antenna with a large impedance bandwidth, good impedance matching, increased radiation efficiency, and high gain. The antenna is designed on an FR4_epoxy substrate with a compact size of 30 × 20 × 0.8 mm^3, a dielectric constant of 4.4, a thickness of 0.8 mm, a loss tangent of 0.02 and fed by a 50 Ω microstrip feed line. It is analyzed and simulated at the operating frequency of 5.2 GHz for ultra-wideband (UWB) (3.1–10.6 GHz) applications using high-frequency structure simulator (HFSS) software. The simulation results reveal that the antenna offers a broad bandwidth of 19.9 GHz (3.10 GHz to 23 GHz), a gain of 7.97 dB with an efficiency of 0.9651 (96.51%). The radiation pattern is bidirectional in both the E-plane and H-plane. Hence, the proposed antenna is very promising for future IoT applications due to its compact size and wide bandwidth characteristics. It also enhances connectivity and performance, lowers interference, opens up new applications, and encourages the widespread use of IoT technology, ultimately leading to the development of a more sophisticated and connected society.*

Keywords: *IoT; hybrid patch antenna; DGS; broad bandwidth; microstrip feed line.*

1. INTRODUCTION

The Internet of Things (IoT) has frequently become a vital part of our daily lives since it integrates various devices making communication between them easy. As the number of IoT devices grows, there is a larger need for communication systems that can handle the massive amount of data being produced by these devices [1]. UWB technology is a desirable option for IoT communication systems due to its large bandwidth, rapid data rate transmissions, low power consumption, low complexity, minimum interference, effective spectrum usage, secure connection, and straightforward circuitry. It fulfills the unique needs of IoT applications and offers dependable and effective wireless connectivity for a variety of IoT devices [2].

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Microstrip patch antennas (MPAs) are a popular choice for UWB applications due to their compact size, low profile, and ease of integration. They provide an efficient and practical solution for achieving reliable wireless communication in devices where space is limited and integration with other planar circuitry is required. MPAs are planar antennas made of a conducting patch positioned on a substrate above a ground plane. They are appropriate for ultra-wideband (UWB) applications because they have a broad frequency range of operation, ranging from a few hundred MHz to several GHz. There are several methods to feed the patch antenna, including coaxial, proximity coupling, aperture coupling, and microstrip feed lines. The most popular technique for feeding MPAs is the microstrip feed line due to its reliability, simplicity, and ease of integration compared to other feed line strategies.

Indeed, a lot of research has been done on ultra-wideband (UWB) antennas for Internet of Things (IoT) applications to improve various performance factors like gain, bandwidth, and radiation efficiency. To make these enhancements, researchers investigated a variety of methods and alterations. Studying alternative patch antenna materials and forms is one strategy. To enhance the effectiveness of the antenna, for instance, researchers explored the usage of circular, rectangular, or triangular patches as well as various dielectric materials. The shape and material of the antenna can be carefully chosen to produce superior bandwidth and gain qualities. Modified patch designs have also been investigated as a technique to boost the antenna's effectiveness. These modifications could include adding slots, fractal patterns, or meandering structures to the patch. These modifications can help increase the antenna's emission pattern, reduce its size, or increase its bandwidth. Partial ground planes and defective ground structures (DGS) have also been employed to enhance the performance of the antenna. By including slots or patterns in the ground plane, the radiation properties of the antenna can be changed, resulting in higher gain and bandwidth. The performance of UWB antennas has also been improved by using split ring resonators (SRR), shorting pins, meandering slots, and metamaterials. These strategies attempt to alter the electromagnetic properties of the antenna construction to achieve the intended characteristics, such as increased bandwidth or radiation efficiency.

Numerous feeding strategies have been explored to improve the functioning of UWB antennas. Various feed systems, proximity-coupled feeding, and aperture-coupled feeding are some of these techniques. By properly planning the feeding procedure, the antenna can achieve better impedance matching, higher gain, and better radiation properties.Ultimately, a variety of methods and alterations have been investigated by researchers to improve the gain, bandwidth, and radiation efficiency of UWB antennas for IoT applications. The performance of UWB antennas for various IoT applications is being optimized by researchers by incorporating various forms, materials, updated patch designs, ground plane structures, and feeding methods.

In this paper, an ultra-wideband rectangular patch antenna using hybrid strategies (HS) for future IoT applications is proposed. The main goal of this article is to reduce the size of the antenna and enhance its radiation properties, including bandwidth, gain, and efficiency. By achieving these improvements, it is anticipated that a more advanced and interconnected society can be developed. HS is formed by a slotted patch and partial ground with defected ground structure (DGS). It provides several advantages like compact size, wide bandwidth, and good impedance matching, suppressing unwanted radiation modes, improved gain, and radiation efficiency.

The remaining portions of the article are structured as follows: Section 2 contains the literature review. In Section 3, the materials, methodologies, and simulation software selection process are described. The parameters of a patch antenna are presented in Section 4. In Section 5, the antenna construction is explained. Results and discussion from the simulation are shown in Section 6. A comparison of the proposed work with recently released works is offered in Section 7. Finally, Section 8 describes the conclusion.

2. LITERATURE REVIEW

Several studies have investigated the design and performance of ultra-wideband rectangular patch antennas for IoT applications. For instance, a rectangular UWB antenna on FR4 and a denim textile substrate were designed for wearable IoT applications [3]. The designed antenna attained a 2.9 GHz – 11 GHz bandwidth with a maximum gain of 5.12 dBi and 3.57 dBi, respectively. An Ultra-wideband coplanar waveguide-fed (CPW) monopole antenna with a partial rectangular patch and the round corner of the rectangular slot for IoT Applications was proposed. The antenna demonstrated a bandwidth of 163% (0.75 GHz to 6.5 GHz) with a maximum gain of 4 dBi [4]. For Internet of Things applications, a key-shaped ultra-wideband antenna (UWBA) was reported [5]. The antenna achieved a bandwidth of 8 GHz (2.6 GHz – 10.6 GHz)

An incredibly small ultra-wideband (UWB) monopole microstrip patch antenna using a modified ground plane with a monopole pair for a wireless body area network (WBAN) was presented [6]. The antenna had a bandwidth of 124.67% (3.48 –15 GHz) with a peak gain of 7.2 dBi. The integration of an annular ring ultra-wideband antenna and a metallic through an array for Internet of Things applications was demonstrated [7]. The antenna's peak gain was 9 dBi, and its bandwidth was 108% (3.1 – 10.3 GHz). A tiny ultra-wideband monopole antenna using a microstrip-fed rectangle radiator with an L-shaped stub and a ground plane with a rectangle slit were exhibited for Internet of Things (IoT) applications [8]. The antenna had a gain of – 0.16 dB and a bandwidth of 122% from 3.1 GHz to more than 12 GHz.

A coplanar waveguide (CPW) fed flexible UWB antenna with a bandwidth of 161.44% (3.2 GHz to 30 GHz) and a gain of 4.87 dB was proposed [9]. The antenna was designed using a circular patch with a double-stepped symmetric ground plane. The simulation results showed that the antenna had a good impedance matching and radiation pattern. For compact-size Internet of Things (IoT) gadgets, an adjustable paper-based wideband antenna was seen [10]. A 12.9 GHz (0.1 GHz to 13 GHz) bandwidth was obtained using the antenna. An innovative ultra-wideband (UWB) planar monopole antenna fabricated on Roger RT/5880 substrate was unveiled for use in miniature Internet of Things (IoT) scenarios [11]. It has an impedance bandwidth of 9.53 GHz, spanning from 3.026 GHz to 12.556 GHz with a gain of 2.55 dBi.

A lightweight UWB antenna covering two bands of frequencies from 1.0 to 3.65 GHz was suggested [12] for Internet of Things (IoT) application platforms. The antenna is just about 25 mm by 35 mm by 1.6 mm in size. A UWB antenna working across a wide band of the spectrum from 3.04 to 10.70 GHz was suggested for use with UWB and IoT devices [13]. An insignificant antenna with a radiation efficiency of 60% and a smaller size of 25 mm × 40 mm × 1.6 mm was recommended for IoT applications [14]. A distinctive ultra-wideband CPW feed etched on the FR4 substrate with a circular patch and a resonator was described [15] for Internet of Things (IoT) wireless uses. The antenna attained a bandwidth of 8.46 GHz (3.54 GHz to 12 GHz). A portable eight-port Ultra-Wideband (UWB) MIMO antenna based on Metallic Via (M-Via) was developed [16] for Internet of Things (IoT) purposes. A bandwidth of 9 GHz (3 GHz to 12 GHz) and a gain of 0 dB to 7.5 dB were acquired by the antenna.

A small, fractal patch antenna with a trident form was made using the ground electromagnetic band gap (EBG) modification for a wide range of IoT-based applications

[17]. The antenna was designed to perform with a gain of 2.52 dBi and a bandwidth of 11.71 GHz (1.59 GHz to 13.3 GHz). A 4-element foldable MIMO antenna was developed for IoT applications [18]. A 10.6 GHz (2.4 GHz – 13.0 GHz) impedance bandwidth was obtained by the antenna. A partial ground with a Defected Ground Structure (DGS) and ideal and practical switching elements were used to design a UWB Antenna for IoT applications [19]. The antenna was able to achieve a bandwidth of 1.02 GHz (3.15 – 4.17 GHz) and 7.97 GHz (7.03 – 15 GHz), 5.22 GHz (2.95 – 8.17 GHz), and 5.87 GHz (9.13 – 15 GHz) respectively, and a maximum gain of 2.83 dB, 5.12 dB, and 5.2 dB respectively. A dual-band microstrip patch antenna in the form of a rook was recommended for Internet of Things applications [20]. The antenna was able to attain a gain of 4.42 dB with a radiation efficiency of 69%, as well as bandwidths of 2.6 GHz (6.4 GHz to 9 GHz) and 1.5 GHz (3.5 GHz to 5 GHz), respectively.

3. MATERIALS AND METHODS

3.1. FR-4 EPOXY MATERIAL

Flame Retardant-4 (FR-4) epoxy resin is typically employed as the substrate material in antenna designs, particularly those for microstrip patch antennas. It is a popular choice for antenna applications due to its low price, low dielectric constant, and low loss tangent. It is useful for microstrip patch antennas that FR-4 epoxy has a low dielectric constant, which typically ranges from 3.8 to 4.8. The electrical length of the patch antenna grows while the electromagnetic wave propagation velocity is decreased. This makes it possible for the antenna to resonate at a lower frequency, which is frequently preferred for many applications. Microstrip patch antennas that operate at high frequencies require the FR-4 epoxy's low loss tangent, which is typically around 0.02. To retain good antenna performance, a material must have minimal signal losses, which is shown by a low-loss tangent. High losses can severely reduce an antenna's efficacy and efficiency. The metal patch is normally positioned on one side of the substrate while the ground plane is placed on the other in the design of a microstrip patch antenna utilizing FR-4 epoxy as the substrate material. The feed line, which supplies the antenna with the desired signal, is often a thin metal strip on the patch's back. The patch, ground plane, and feed line are exactly modified, shaped, and aligned to provide the frequency, bandwidth, and radiation pattern of the antenna that is needed.

3.2. HYBRID TECHNIQUE

The hybrid strategy employs many different strategies to boost the performance of microstrip patch antennas, including partial grounding, defected ground structure (DGS), and slotted patch methods. To achieve specific performance goals, these methods can be combined, and each offers advantages of its own. With the slotted patch approach, the patch is altered by the addition of slots or holes, changing the antenna's impedance, current distribution, and radiation pattern. By utilizing this technique, the antenna's bandwidth and gain can be improved, making it suitable for high bandwidth uses like ultra-wideband (UWB) patch antennas.

The partial grounding method involves removing a portion of the ground plane under the patch. The antenna's impedance bandwidth and radiation efficiency may both be enhanced by this adjustment, which also alters the electromagnetic field distribution. It is widely used in high-frequency microstrip patch antennas that demand a broad impedance bandwidth. The defective ground structure (DGS) method creates a periodic pattern of slots or holes in the ground plane. This design acts as a stop-band filter, improving the performance of the antenna by preventing the propagation of surface waves. The DGS technique is frequently employed in high-frequency microstrip patch antennas that require selectivity and rejection of undesired frequencies. The hybrid approach combines various techniques to benefit from each approach's unique advantages. As a demonstration, a microstrip patch antenna may have a slotted patch design for greater bandwidth and gain, a partial ground plane for greater impedance bandwidth, and a DGS for greater selectivity and rejection of undesired frequencies. To obtain the desired performance characteristics, it is possible to modify the individual design factors, such as the size, shape, and spacing of slots or holes. In general, the hybrid strategy enables the improvement of the microstrip patch antenna performance by combining various techniques, such as the slotted patch method, partial grounding method, and defected ground structure (DGS) method, to meet specific performance objectives in terms of bandwidth, impedance, and discrimination.

3.3. CHOICE OF SIMULATION SOFTWARE

Patch antenna design and simulation typically involve the use of software tools like HFSS, CST Studio Suite, FEKO, ADS, Sonnet, and others. To design and analyze antennas, each of these tools offers a variety of features and capabilities. HFSS, in particular, is widely used in the industry for its ability to leverage the Finite Element Method (FEM) to solve Maxwell's equations accurately. This enables engineers and scientists to forecast and examine the behavior of electromagnetic structures, including various kinds of antennas.

The FEM-based technique in HFSS enables users to model and simulate many antenna designs, including microstrip patch antennas, wire antennas, horn antennas, and more. It offers a complete range of tools for the development of geometry, meshing, specifying boundary conditions, setting up solvers, running simulations, and post-processing of results. By utilizing HFSS or equivalent software tools, engineers and scientists can assess patch antenna performance, make design changes, and get additional knowledge about the electromagnetic behavior of these antennas. With the use of these tools, users can view and assess S-parameters, radiation patterns, impedance matching, and other important properties. Thus, HFSS and other software tools play a crucial role in the design and modeling of patch antennas, providing engineers and researchers with practical tools to explore and enhance antenna performance. There are six essential stages for creating and carrying out an accurate HFSS simulation, as shown in Fig. 1.

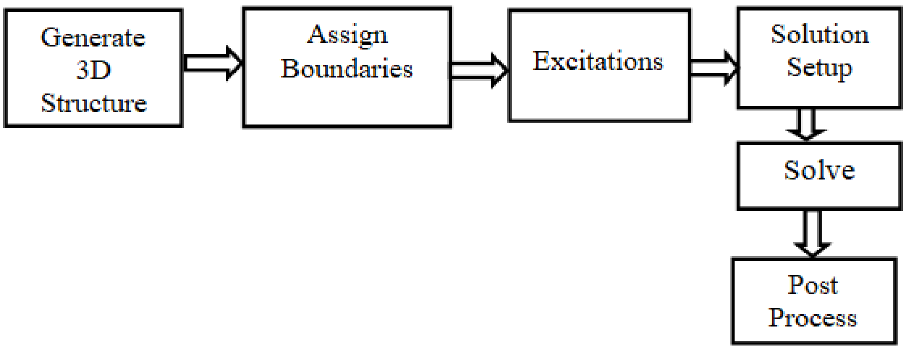


Figure 1. Six vital steps for developing and executing a realistic HFSS simulation

4. PARAMETERS OF A PATCH ANTENNA

The following three factors are crucial for the design of a patch antenna:

1. Frequency of operation(f_0):

For the design, 5.2 GHz has been chosen as the resonant frequency.

2. Dielectric material (ε_r)

The dielectric material chosen for the design is FR4_epoxy, which has a dielectric constant of 4.4 and a loss tangent of 0.02. The antenna's size can be decreased by using a substrate with a high dielectric constant.

a. Thickness (height) of dielectric substrate (h)

The antenna must be lightweight to function properly. Therefore, 0.8 mm is chosen as the dielectric substrate's thickness.

Step 1.*Calculation of the patch width (W_p):*
The following equation provides the width of the rectangular patch antenna [21]:

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

where, c = light speed in a vacuum, f_0 = resonant frequency

Step 2. *Calculation of effective dielectric constant (ε_{reff}):*
The effective dielectric constant is provided by the following equation as [21]:

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

where,
$\varepsilon_{\mathrm{reff}}$ = 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 given as [21]:

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

Step 4.*The computing of the patch length extension(ΔL_p):*
The equation below gives the patch length extension [21]:

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

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

The actual length of the patch antenna can be calculated as [21]:

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

The primary parameter of the patch is shape, which inherently influences most antenna properties. The bandwidth is significantly impacted by the patch width, although the resonant frequency is only slightly affected. As a result, the width of the patch and the thickness of the substrate are of the utmost importance for increasing the antenna's radiation efficiency and bandwidth.

Step 6. *Determining the dimensions of the ground plane*

The dimensions of the ground plane are usually calculated using the following formulas [21]:

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

where, L_p and W_p are the length and the width of the patch antenna.

The following table lists the several characteristics of the patch antenna, including its shape, the type of dielectric it is made of, its length and width, its thickness, and the dimensions of its slot.

Table 1. Parameters of a rectangular patch antenna

No.	Parameter	Dimensions [mm]
1	Substrate width (Ws)	20
2	Substrate width (Ls)	30
3	Substrate thickness (h)	0.8
4	Patch width (W_p)	18
5	Patch length (L_p)	14
6	Microstrip feedline width (W_f)	2
7	Microstrip feedline length (L_f)	15
8	Partial ground plane width (Wg)	20
9	Partial ground plane length (Lg)	14
10	Partial ground plane slot width (W_{g1})	2
11	Partial ground plane slot length (L_{g1})	3
12	Patch rectangular slot 1 width (W_{p1})	2
13	Patch rectangular slot 1 length (L_{p1})	8
14	Patch rectangular slot 2,3& 4 width ($W_{p2} = W_{p3} = W_{p4}$)	0.5
15	Patch rectangular slot 2,3& 4 length ($L_{p2} = L_{p3} = L_{p4}$)	7
16	Patch rectangular slot 5& 6 width ($W_{p5} = W_{p6}$)	6.5
17	Patch rectangular slot 5& 6 length ($L_{p5} = L_{p6}$)	0.5
18	Corner truncation length (a)	8.48

5. DESIGN OF A RECTANGULAR PATCH ANTENNA

The following are the crucial design parameters:

- Resonant frequency (f_0) = 5.2 GHz
- Dielectric constant (ε_r) = 4.4
- Substrate thickness (h) = 0.8 mm

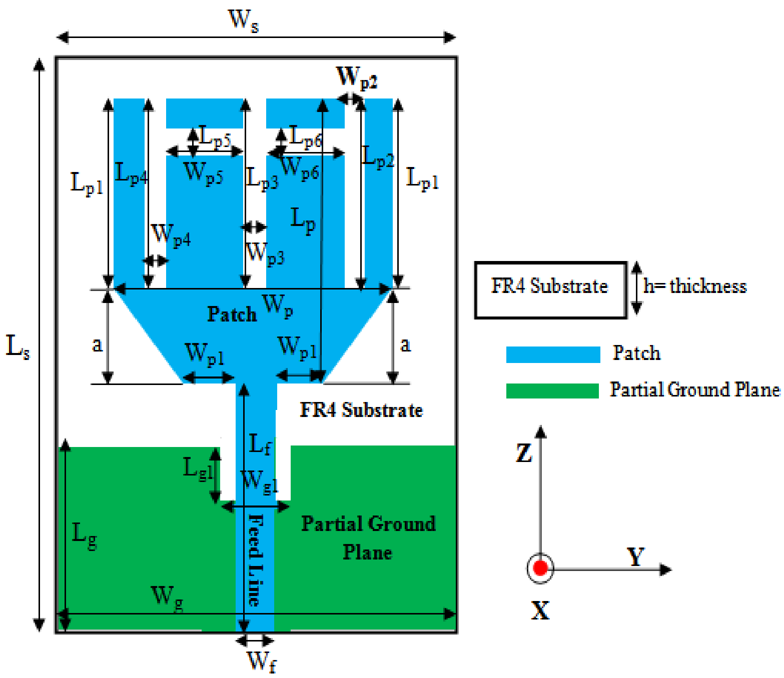


Figure 2. Proposed antenna structure

The parameters listed in Table 1 have been employed to design and simulate a rectangular patch antenna in high-frequency structure simulator version 15 (HFSSv15) with a resonance frequency of 5.2 GHz. FR4 epoxy is a material that is utilized as the substrate. The preferred material for the majority of PCB applications is FR4 epoxy glass. The material is appropriate for a variety of applications needing electronic components since it is mechanically superior and reasonably priced.

6. SIMULATED RESULTS AND DISCUSSION

The simulated outcomes of the radiation properties graphs for the aforementioned design are provided below.

6.1. RETURN LOSS

The return loss of an antenna is a measure of the amount of power reflected from the antenna due to impedance mismatch. It quantifies the efficiency of power transfer between the antenna and the transmission line or feeding network. Return loss is typically expressed in decibels (dB) and is calculated as:

$$\text{Return Loss (dB)} = 20\log10\ (|\rho|)$$

where, ρ is the reflection coefficient of the antenna, representing the ratio of the reflected power to the incident power. More power is reflected from the antenna as return loss increases. This generally implies that there is an impedance mismatch between the feedline and the antenna. A better impedance match between the feedline and the antenna and higher power transfer efficiency are both indicated by a declining return loss, which results in less power returning from the antenna. A return loss of less than –10 dB is often desirable in antenna design for effective power transfer and minimal reflection. For example, a return loss value of –10 dB indicates that less than 10% of the incoming power is reflected, with the remaining 90% being properly absorbed by the antenna.

Fig. 3 exhibits the return loss based on the simulation findings. The suggested antenna gives a variety of resonance frequencies, including 3.5 GHz, 6.2 GHz, 6.9 GHz, 7.7 GHz, 12 GHz, 15 GHz, 17.7 GHz, 20.10 GHz, and 22 GHz, with return losses of –20.16 dB, –23.16 dB, –24.72 dB, –29.21 dB, –18.80 dB, –12.64 dB, –21.80 dB, –13.03 dB and –13.08 dB, respectively. A decreased return loss of –29.21 dB at 7.7 GHz is achieved with the proposed antenna. This return loss value of –29.21 dB is quite satisfactory because it is beneath (less than) the –10 dB lowest stated level for a practical and realistic microstrip patch antenna design and shows that the smallest amount of power (0.12%) returns from the antenna to the source input port.

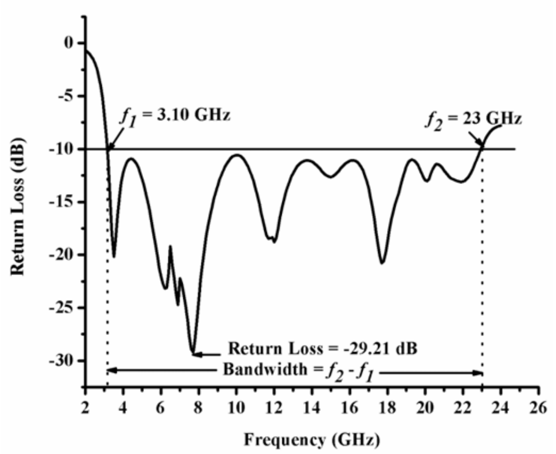


Figure 3. Return loss plot for the proposed antenna

6.2. BANDWIDTH

The bandwidth is the frequency range over which the antenna can operate efficiently. It is generally expressed as the percentage of the center frequency and is calculated as follows:

$$\text{Bandwidth (\%)} = (f_2 - f_1) / f_c \times 100\%$$

where, f_1 and f_2 are the lower and upper frequencies, respectively, and $f_c = f_1+f_2/2$ is the center frequency. The suggested antenna's fractional bandwidth can be calculated using the return loss graph. The proposed antenna attains a fractional bandwidth of 152.49% (3.10 GHz – 23 GHz), which is better than that presented in refs. [4 – 5, 7, 9, 11, 13, 15, 16], and nine (9) resonance frequencies of 3.5 GHz, 6.2 GHz, 6.9 GHz, 7.7 GHz, 12 GHz, 15 GHz, 17.7 GHz, 20.10 GHz, and 22 GHz. The plot also shows that the recommended antenna has an efficient operating frequency of 7.7 GHz and a return loss of –29.21 dB.

6.3. VOLTAGE STANDING WAVE RATIO (VSWR)

The Voltage Standing Wave Ratio (VSWR) is a parameter that quantifies the impedance match between an antenna and the transmission line or feeding network. It provides a measure of the amount of power reflected by the antenna due to impedance mismatch. The VSWR value provides information about the extent of the impedance mismatch. A lower VSWR indicates a better impedance match and efficient power transfer, while a higher VSWR signifies a higher degree of reflection and a poor impedance match.

In practical terms, a lower VSWR value (close to 1) is desired, as it indicates minimal reflections and efficient power transfer. Typically, VSWR values below 2:1 are considered acceptable in many applications, while values closer to 1:1 represent a nearly perfect impedance match. VSWR values greater than 2:1 may lead to increased losses, reduced efficiency, and potential performance degradation. Fig. 4 illustrates the recorded VSWR of the planned antenna, which is 1.07 dB at the resonant frequency of 7.7 GHz.

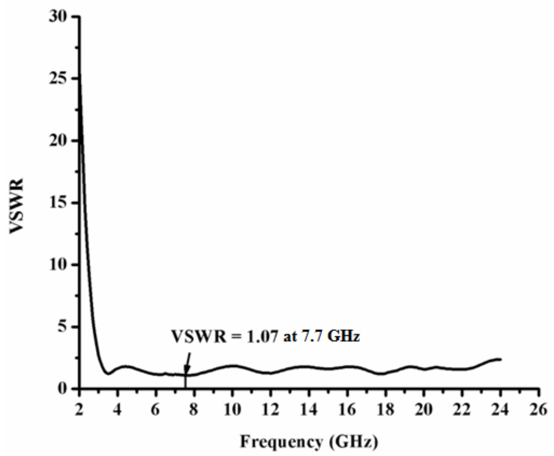
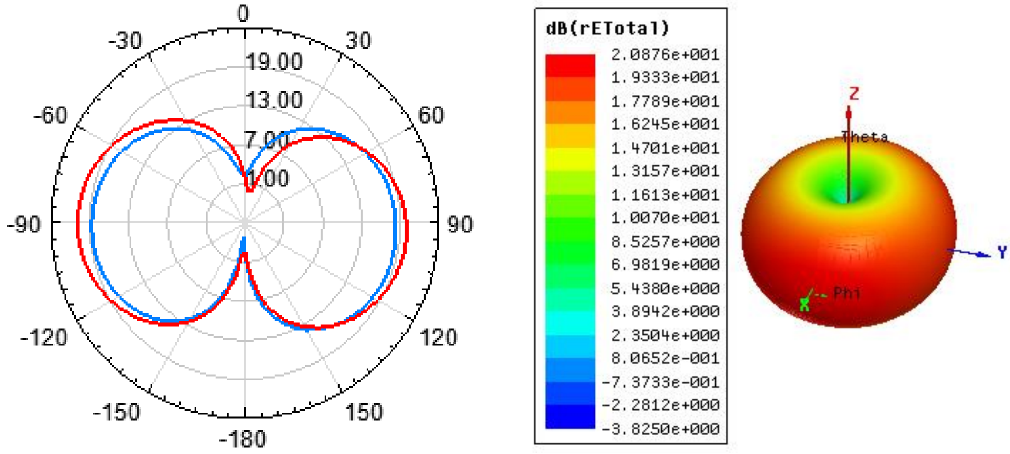


Figure 4. VSWR plot for the proposed antenna

6.4. RADIATION PATTERN

The radiation pattern of an antenna describes the directional distribution of radiated electromagnetic energy in the space surrounding the antenna. It illustrates how the antenna's radiated power is distributed as a function of direction. The radiation pattern is typically represented as a graphical plot in two dimensions (polar plots) or three dimensions.

Polar plots show the radiation pattern in a plane containing the antenna's axis, while 3D patterns provide a more comprehensive representation, showing the radiation in all directions around the antenna. Figs. 5(a) and (b) show a simulated 2D and 3D view of the far-field radiation patterns of the antenna. Figure 5(a) demonstrates that the proposed antenna emits radiation in both the E-plane and the H-plane in a bidirectional manner. The E-plane and H-plane have been denoted by red and blue colors, respectively. The colors red, blue, yellow, and green in Fig. 5 (b) also represent the different radiation levels, from highest to lowest. The color red denotes the largest radiation level, while the color blue denotes the smallest. The envisioned antenna's 20.876 dB peak radiated power and omnidirectional radiation pattern suggest that ultra-wideband IoT systems will benefit greatly from it.



(a) (b)

Figure 5. Simulated (a) 2D and (b) 3D radiation patterns for the proposed antenna

6.5. GAIN AND DIRECTIVITY

The gain of an antenna is a measure of its ability to direct or concentrate the radiated power in a particular direction. Antennas with higher gain have a more focused radiation pattern and can transmit or receive signals with greater power in a particular direction. This is beneficial for applications that require long-range communication or signal reception in a specific direction. However, it’s important to note that antenna gain is always accompanied by a corresponding reduction in radiation in other directions.

Directivity is a measure of how well an antenna focuses or concentrates its radiated power in a particular direction. It quantifies the antenna’s ability to direct its energy toward a specific target or receive signals from a specific direction. The directivity of an antenna indicates the extent to which it can focus its radiation in a specific direction. A higher directivity implies a more concentrated radiation pattern, meaning that more power is directed towards the desired direction and less is radiated in other directions. This concentration of power allows for increased signal strength, longer communication range, and improved signal-to-noise ratio. A simulated gain and directivity of the suggested antenna are shown in Figs. 6 and 7.

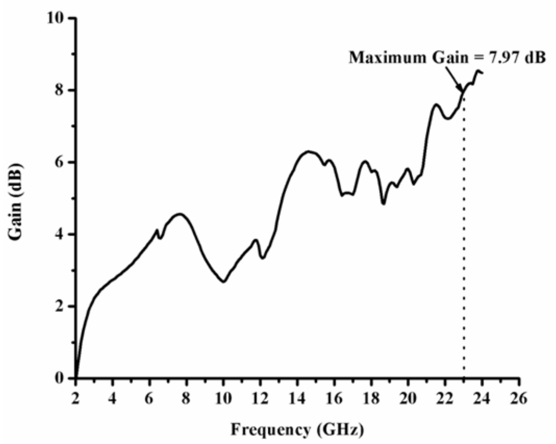


Figure 6. Simulated gain for the proposed antenna

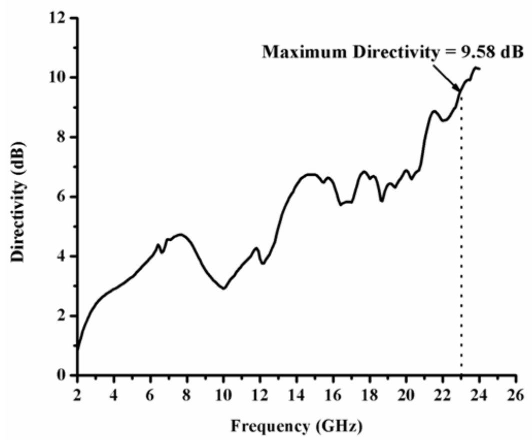


Figure 7. Simulated directivity for the proposed antenna

As can be observed from Figs. 6 and 7, the suggested antenna has a gain range from 2.29 dB to 7.97 dB and a directivity range from 2.46 dB to 9.58 dB within the operating band of 3.10 GHz to 23 GHz. The proposed antenna yields a maximum gain of 7.97 dB, which is greater than that in the references [4 – 6, 9, 11, 13,15, 16], and a peak directivity of 9.58 dB at 23 GHz.

6.6. EFFICIENCY

The efficiency of an antenna is a measure of how effectively it converts the input power into radiated power. It quantifies the antenna's ability to minimize losses and maximize the amount of power that is radiated into free space. Efficiency is expressed as a ratio or percentage and is calculated as:

$$\text{Efficiency (dimensionless)} = \text{Radiated Power} / \text{Input Power}$$

$$\text{Efficiency (\%)} = (\text{Radiated Power} / \text{Input Power}) \times 100$$

The radiated power represents the power that is emitted by the antenna into the surrounding space. In contrast, the input power is the power supplied to the antenna from the transmitter or the feeding network. High antenna efficiency is desirable as it ensures that the majority of the input power is radiated, minimizing losses and maximizing the effective radiated power. Efficient antennas can improve the overall performance of wireless communication systems by increasing the signal strength, range, and reliability. The efficiency of the anticipated antenna is shown in Fig. 8.

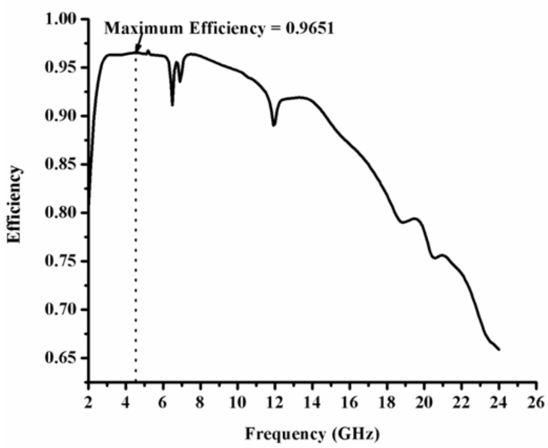


Figure 8. Simulated efficiency for the proposed antenna

As seen, within the frequency spectrum of 3.10 GHz to 23.00 GHz, the efficiency varies from 0.731 (73.1%) to 0.9651 (96.51%). The antenna outperforms the efficiency depicted in references [9, 11, 16] by a factor of 96.51% at 4.60 GHz. It implies that the suggested antenna can efficiently radiate the input energy into free space.

7. COMPARISON OF PROPOSED WORK WITH SOME OF THE RECENT WORKS

In Table 2, the effectiveness of the suggested antenna and some of the newly designed UWB patch antennas for Internet of Things (IoT) applications are compared. This table shows that the current antenna has a large efficiency of 96.51% and a gain of 7.97 dB, which are both higher than the references [9, 11, 16] and [4 – 6, 13, 15], respectively. However, the offered antenna attains a comparatively similar efficiency to that seen in the references [6, 7, 13]. In contrast to the reference [4, 5, 7, 9, 11, 13, 15, 16], the bandwidth is found to be significantly higher. The proposed antenna is smaller in size than the references [4-7, 9, 13, 15, 16] and it has a wider bandwidth of 19.9 GHz (3.10 GHz to 23 GHz), which is superior to that of the existing antennas.

Table 2. Comparisons of present work with previously published work

Refs.	Antenna Size [mm^3]	Operating Bandwidth [GHz]	Bandwidth [GHz]	Gain [dB/dBi]	Efficiency [%]	Methods
[4]	138× 40 × 1.6	0.75 - 6	5.25	1 dBi - 4dBi	-	CPW slot, partial rectangular patch, and the round corner of the rectangular slot
[5]	44 × 44 × 1.6	2.6 - 10.6	8	-	-	key-shaped
[6]	20 × 15 × 0.5	3.48 - 15	11.52	2.3 - 7.2 dBi	77 - 95	flexible Rogers RT-5880 dielectric substrate-basedmodified ground plane with a monopole pair
[7]	34 × 34 × 1.6	3.1 - 10.3	7.2	9 dBi	97	annular ring and a metallic through an array
[9]	33.1× 32.7 × 0.254	3.2 - 30	26.8	4.87 dB	86.61	circular patch with the double-stepped symmetric ground plane
[11]	15 × 17 × 1.548	3.026-12.556	9.53	2.55 dBi	90	Rogers RT-5880 based partial ground plane
[13]	47 × 25 × 0.135	3.04 - 10.7	7.66	3.94 dBi	95.7	PET substrate-based inside-cut feed structure
[15]	35 × 25 × 1.6	3.54 - 12	8.46	3.93 dBi	-	circular patch with a resonator and CPW feeding
[16]	54 × 54 × 0.3	3 - 12	9	0- 7.5 dB	70 - 90	Metallic Via(M-Via) integration
This work	30 × 20 × 0.8	3.10 - 23	19.9	7.97 dB	96.51	Hybrid techniques (Slotted patch, partial ground plane, and defected ground plane)

8. CONCLUSIONS

In this paper, an ultra-wideband rectangular patch antenna using hybrid strategies for future Internet of Things (IoT) applications has been successfully designed and analyzed. The proposed antenna design offers several benefits, such as compact size, large bandwidth, high gain, and improved radiation efficiency. Simulation results demonstrate a bandwidth of 152.49% (3.10–23 GHz), a peak gain of 7.97 dB, and a radiation efficiency of 96.51%. These characteristics make the antenna suitable for future IoT applications, where wide bandwidth, large gain, and compact size are essential. The recommended antenna design using hybrid methods has the potential to contribute to the development of IoT systems, leading to a more connected and smarter society. The antenna can also be used for various wireless applications, including X band (8 GHz to 12 GHz), C band (4 GHz to 8GHz), Ku band (12 GHz to 18 GHz), S band (2 GHz to 4 GHz), STM band (6 GHz to 6.17 GHz), WiMAX (3.4 GHz to 3.69 GHz, 5.25 GHz to 5.85 GHz), Wi-Fi, WLAN (5.15 GHz to 5.825 GHz), radio astronomy, military communications, communications and sensors, positioning and monitoring, radar, and satellite communication applications. Future research will focus on prototyping the antenna and evaluating its effectiveness in real-world and computer-simulated environments.

Additionally, embedding the antenna in an array on a single substrate could further enhance its gain, directivity, and efficiency compared to its single equivalent.

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