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Inverse S-Shaped Meander Line Antenna Loaded with Slotted Parasitic Patch and Defected Ground for Internet of Things (IoT) Applications

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ABSTRACT: This paper introduces a microstrip patch antenna operating at the 2.4 GHz ISM (Industrial, Scientific, and Medical) band, specifically suitable for Internet of Things (IoT) applications. The proposed antenna comprises a compact $40 \times 10 \times 1.6\,\text{mm}^3$ design using an inverse S-shaped meander line, defected ground, and slotted parasitic patch to achieve enhanced bandwidth and very low return loss, contributing significantly to antenna design for IoT applications. FR-4 material is used as the substrate for this antenna. The proposed antenna achieves a measured return loss of -24.67 dB at 2.4 GHz, with a bandwidth of 8.75%. Moreover, it provides a gain of 1.14 dB with an efficiency of 73.35%. Also, the designed antenna is integrated into a home automation system to verify its performance in IoT application, and the results are highly satisfactory.

1. INTRODUCTION

In recent era, the development in technology has been spreading quickly. Almost everything will be influenced by the internet. Consequently, the Internet of Things (IoT) has gained attention in monitoring and investigating various sectors [1]. In the age of rapid IoT advancements, numerous applications are being identified across various sectors, including agriculture, security, urban development, home automation, etc. In recent years, compact and promptly coordinated antenna design contributed a great role because of the immense opportunity to utilize many recurrences and multi-capability antennas in IoT operation [2]. As technology expands at a great rate, current wireless systems (IoT devices) perform different tasks and operate at single or multiple frequencies with compact antenna size [3–6]. Different shapes of antennas have been introduced for IoT applications, such as H-shape [7], circular-shape [8], U-shaped open stub [9], M-shaped open stub [10], C-shape [11], D-shape [12], inverted L-shape with partial ground [13], tapered rectangular patch antenna [14], S-shape [17], slots in radiating element antenna [15–20], and slots in ground plane of the antenna [21–24]. Air cavity antenna with a cage-like structure for WLAN application is also implemented [25]. Again, Multiple-Input Multiple-Output (MIMO) antennas are also utilized in IoT fields [26, 27]. The Global Positioning System (GPS), Bluetooth, and Wireless Fidelity (WiFi) technologies utilize planar antennas featuring omnidirectional radiation pattern with an extremely large fractional bandwidth. The key parameters of designing microstrip patch antennas for the 2.4 GHz band include radiation efficiency, bandwidth, radiation pattern, gain, etc. [28, 29]. A wireless network system needs compact, lightweight antennas with affordable fabrication [30]. For this purpose, a compact meander shaped antenna is a perfect example. A uniplanar meandered asymmetric coplanar strip (ACS) fed antenna for 2.5/5 GHz application is proposed in [31]. A compact slotted microstrip antenna having meandering shape can also be utilized [32]. But compact and light antennas also decrease the range of bands, gain, and efficiency which creates another challenge for network applications [33]. The usage of parasitic patch in an antenna is a method of improving bandwidth and peak gain. Gain and bandwidth are increased by roughly 3.3 dB by placing a parasitic patch next to the feeding line [34]. A parasitic patch and an inverted F-antenna operating at 2.4 GHz have been employed in mobile phones, yielding an impedance bandwidth of 90 MHz [35]. A parasitic element for performing in low frequency between 1.6 and 3.45 GHz can increase impedance matching [36]. The bandwidth is increased from 4.3% to 6% and 136% using a microstrip patch antenna with a parasitic patch at a band of 2.99–3.10 GHz and 2.1–11.1 GHz, respectively [35–37]. Using a parasitic patch as the director of low frequency range from 1.61 to 3.45 GHz also increases impedance bandwidth [38]. A 1.6 mm thick FR-4 substrate with a C-load, or capacitive load, is implemented in order to improve the voltage standing wave ratio (VSWR) and peak gain with a fractional bandwidth of 7.23%. This is a well-known technique for performance enhancement [39–40]. For enhancing impedance matching, a partial ground technique was applied on a circular disk monopole antenna [41]. A monopole antenna featuring parasitic element and disk shape provides a higher bandwidth from 2.9 GHz to 20 GHz [42].

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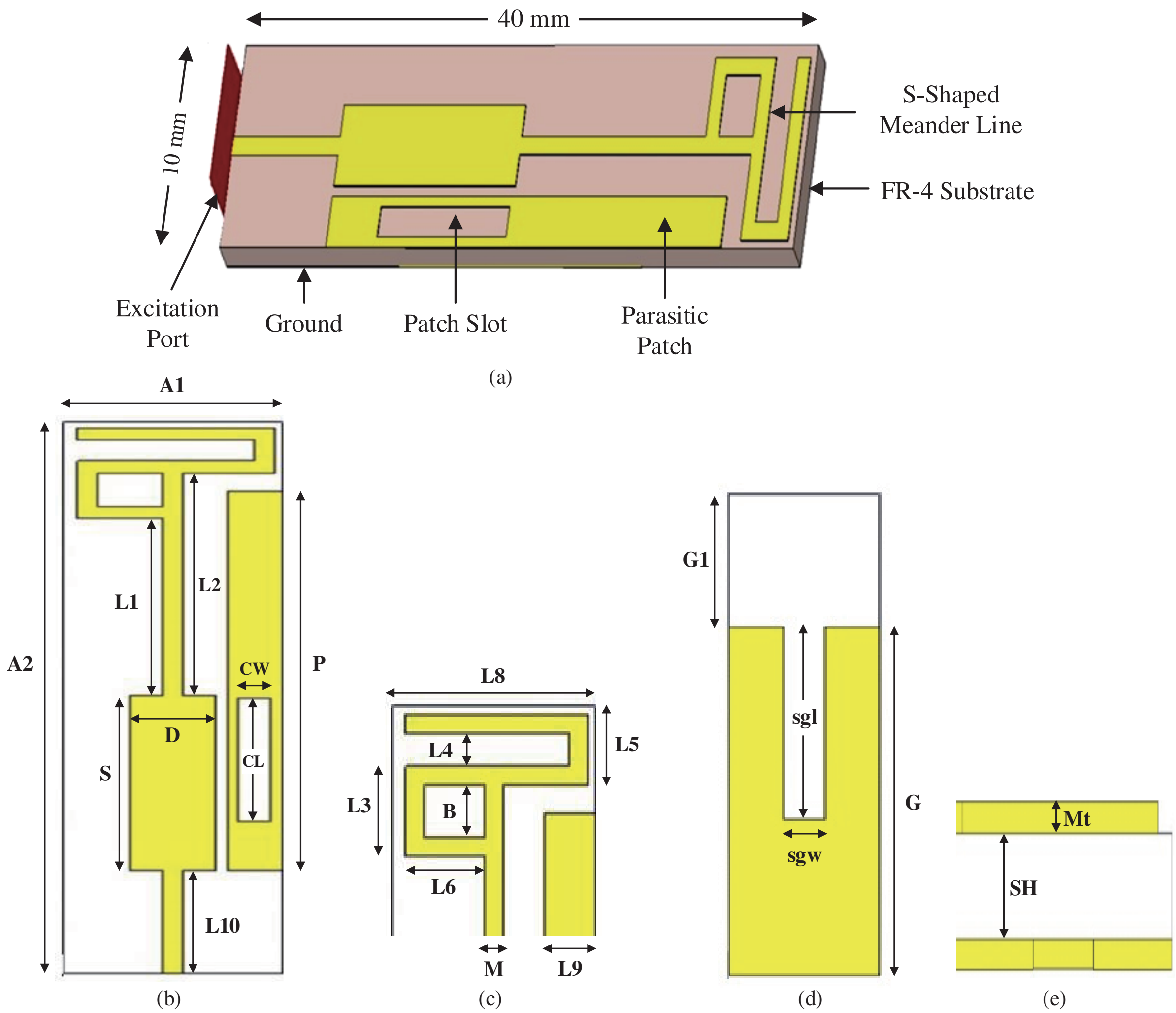


FIGURE 1. Proposed antenna geometry. (a) 3D view, (b) front view, (c) upper part of front view, (d) back view, and (e) side view.

Both meandering and parasitic patches are required for higher impedance matching and bandwidth. In order to obtain both better impedance and fractional bandwidth, a variety of meandering antennas with different diameters have been described and tested for 2.4 GHz [42–45].

This paper proposes an antenna with a compact size, good bandwidth, and impedance matching by the use of an inverted S-shaped meander line coupled to a rectangular form box. It also has a parasitic patch which is connected to the feeding line. A defected ground is incorporated with the purpose of both improving bandwidth and achieving a smaller return loss. This design achieves an enhanced bandwidth of 8.75% and a significantly reduced reflection coefficient of -24.67 dB.

2. ANTENNA DESIGN METHODOLOGY

2.1. Geometry of the Proposed Antenna

The proposed antenna's structure is shown in Figure 1(a). With its inverse S-shaped meander line and rectangular box attached, the antenna has a compact dimension of $40\times10\times1.6\,\text{mm}^3$. This combination provides better bandwidth and perfect impedance matching. A parasitic patch and slotted partial ground are used in this design to obtain improved bandwidth and return loss. The technique of normal feeding is used to feed antenna element. By exciting the feeding line, the antenna allows to operate at the ISM band. An FR-4 material of thickness 1.6 mm, relative permittivity ε_r of 4.4, and loss tangent of 0.025 is used as the substrate to design the proposed antenna.

Moreover, a parametric analysis is performed to analyze the effects of structural parameters on the proposed antenna's performance and measure the optimized values of those parameters.

Figures 1(b) and (c) illustrate the detailed structure of the front part of the proposed antenna. Figure 1(d) shows the rear part of the antenna consisting of partial ground with a slot. Figure 1(e) depicts the side view of the antenna illustrating the height of both substrate and patch. The optimized parameters of proposed antenna are listed in Table 1.

2.2. Parametric Analysis

The effects of several structural parameters on resonant frequencies, bandwidth, efficiency, gain, and impedance match-

TABLE 1. Optimized parameters of the proposed antenna.

Parameter	Size (mm)	Parameter	Size (mm)	Parameter	Size (mm)
$A1$	10.0	$L5$	3.3	M	0.9
$A2$	40.0	$L6$	3.9	Mt	0.08
B	2.4	$L8$	9.0	$G1$	11.0
D	4.0	$L9$	2.5	CW	1.5
$L1$	13.0	$L10$	7.9	CL	9.0
$L2$	16.2	P	27.5	sgw	3.0
$L3$	4.2	G	29.0	sgl	16.0
$L4$	1.5	S	12.6		

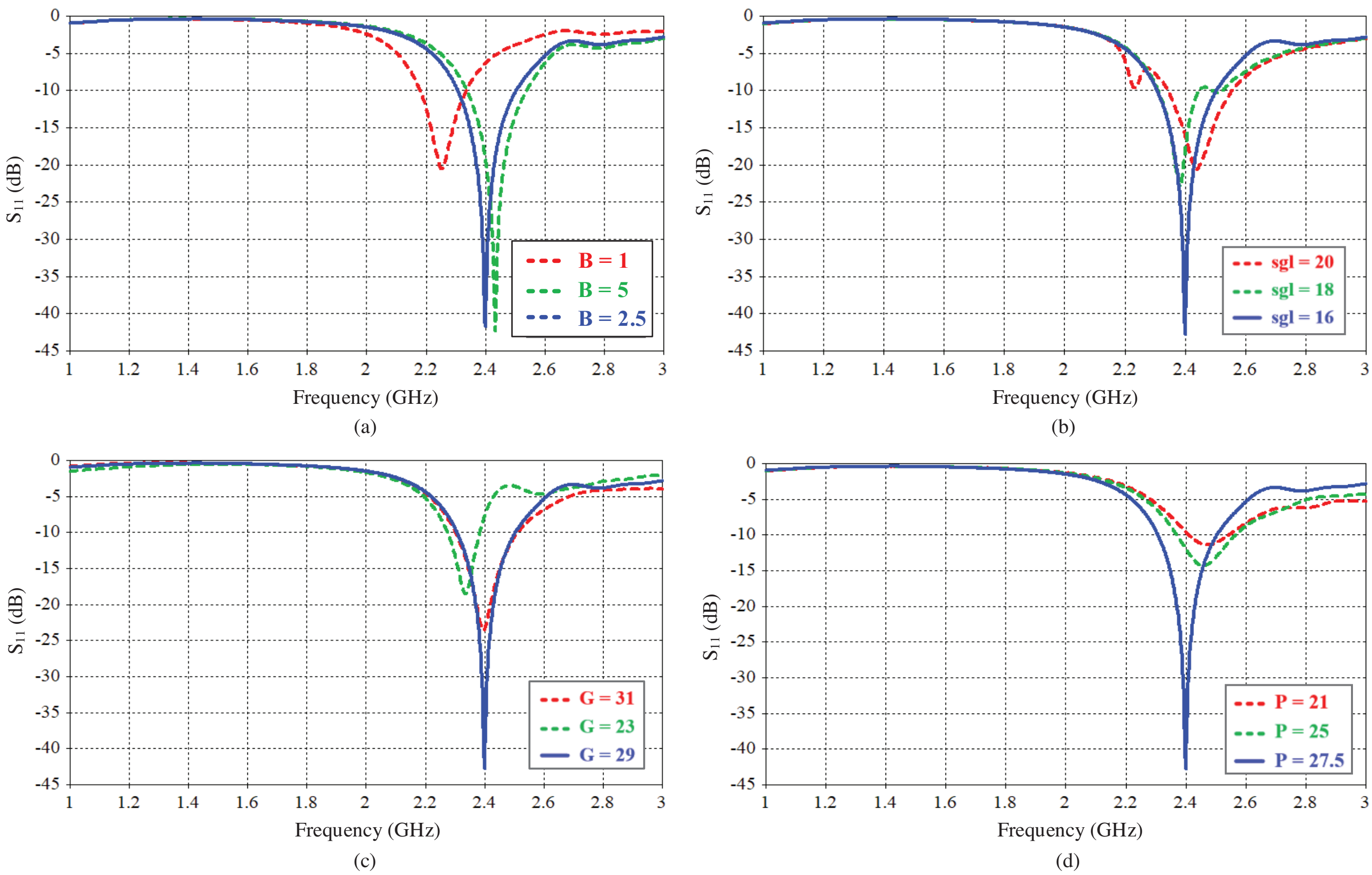
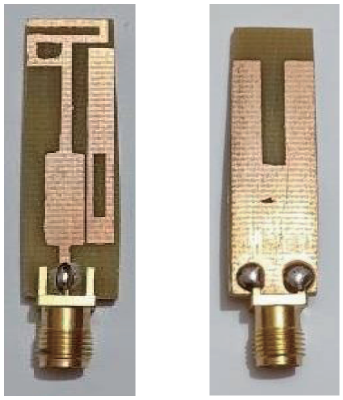


FIGURE 2. The effects of (a) connector height (B), (b) ground slot length (sgl), ground length (G), and parasitic patch length (P) on the return loss (S_{11}) of the proposed antenna.

ing properties are discussed in this section through a detailed parametric analysis. The height of connector between meander line and rectangular box, ground slot length, partial ground height, parasitic patch length, etc., are the factors that affect the proposed antenna parameters. The simulated return loss (S_{11}) with varied height of connector between meander line and rectangular box (B) is shown in Figure 2(a). It is observed that a decrease in B increases the S_{11}, while an increase in B shifts the resonant frequency away from 2.4 GHz. However, when $B = 2.5$ mm, both an improved S_{11} value and enhanced frequency selectivity can be achieved. Figure 2(b) depicts the effect of ground slot height (sgl) on S_{11}. An increase in sgl significantly raises S_{11} and decreases bandwidth, whereas a decrease in sgl has the opposite effect. The value of $sgl = 16$ mm provides both improved bandwidth and a lower S_{11}. Figure 2(c) illustrates the effect of partial ground height (G) on S_{11}.

The decrease in the value of G results in a high S_{11} and low bandwidth. However, the increased value of G provides greater bandwidth but comes with the disadvantage of higher S_{11}. For the value of $G = 29$ mm, both broad bandwidth and sufficiently



(a) (b)

FIGURE 3. (a) Front and (b) back view of the fabricated antenna.

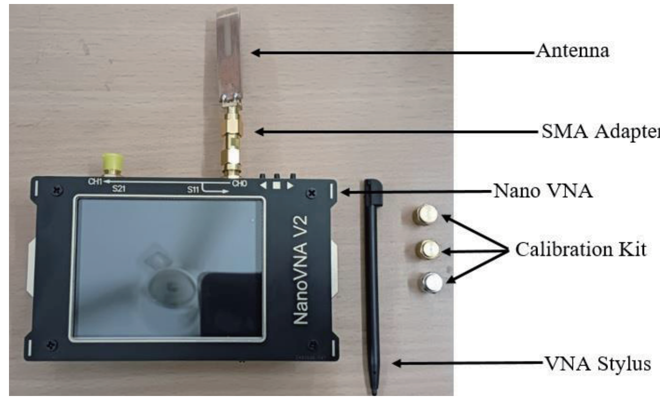
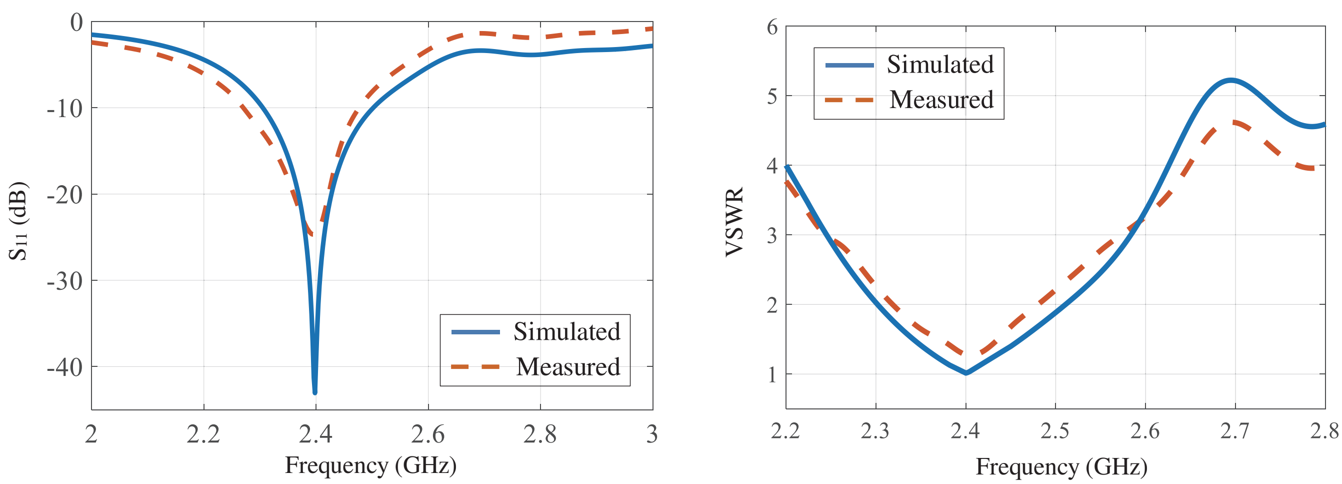


FIGURE 4. Setup for measurement.



(a) (b)

FIGURE 5. Measured and simulated (a) S_{11} and (b) VSWR.

small S_{11} are secured. Figure 2(d) shows the effects of parasitic patch length (P) on S_{11}. The lower the value of P is, the more the S_{11} with low bandwidth is achieved. Increasing the value of P has the opposite effect. According to the results, for low S_{11} and broad bandwidth, the optimized value of P is 27.5 mm.

From the analysis, it can be said that a small S_{11} and hence good impedance matching are obtained for $B = 2.5$ mm, $sgl = 16$ mm, $G = 29$ mm, and $P = 27.5$ mm. Therefore, this set of parameters can be selected as the optimized parameters.

3. RESULTS AND DISCUSSION

3.1. Numerical and Experimental Results

Firstly, the proposed antenna structure is simulated using the updated parameters listed in Table 1 to achieve the antenna performance parameters. Then, the antenna is fabricated, and the S_{11} and VSWR are measured in free space using LiteVNA. Due to the unavailability of pure FR-4 material, glass fiber is used as the substrate. The fabricated antenna structure is represented in Figures 3(a) and (b). Figure 4 depicts the experimental setup for the measurement of the performance parameters of the fabricated antenna.

3.1.1. Return Loss (S_{11} Parameter) and VSWR

Figures 5(a) and (b) illustrate the comparative analysis between measured and simulated S_{11} and VSWRs with respect to frequency. According to the simulated results, the obtained S_{11} of the proposed antenna is -42.81 dB at 2.4 GHz resonant frequency with a band of 2.3–2.5 GHz, i.e., 8.33% bandwidth. It also provides a VSWR of 1.014, indicating very good impedance matching.

According to measured results, the designed antenna offers S_{11} of -24.67 dB at 2.4 GHz with a band of 2.27–2.48 GHz, i.e., 8.75% bandwidth. Again, the measured value of VSWR is 1.27. So, the experimental results slightly deviated from the simulated ones.

It may have happened due to some manufacturing defects, e.g., fabrication dimensioning was not fully accurate, and pure FR-4 was not used as substrate, etc. Some instrumental errors may also have occurred.

3.1.2. Radiation Pattern

Figure 6 illustrates the pattern of radiation of the proposed antenna obtained from simulation. The obtained main lobe mag-

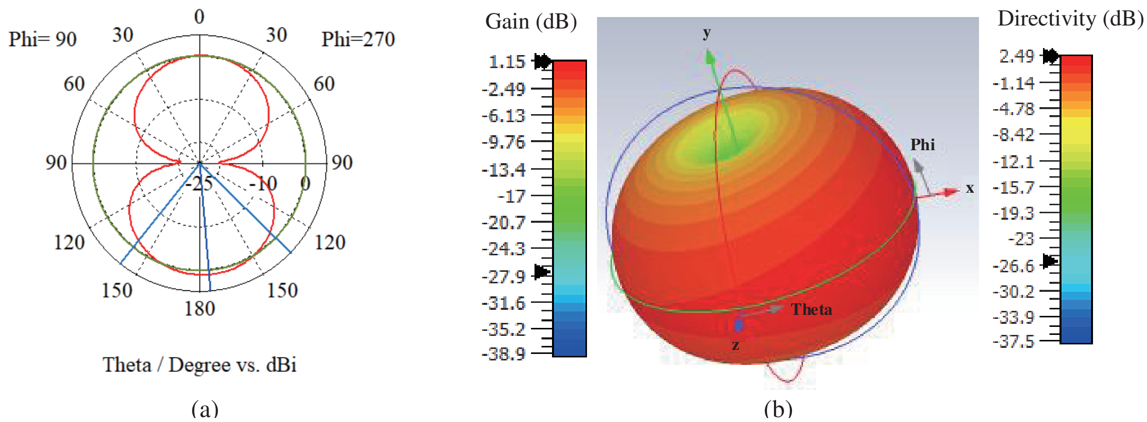


FIGURE 6. Radiation pattern of the antenna at 2.4 GHz in (a) 1D form and (b) 3D form.

nitude of the pattern of radiation is 2.34 dB. This main lobe has the direction along 175° at the resonance frequency of 2.4 GHz. Again, it also has a side lobe whose magnitude is -0.8 dB at the resonant frequency. As the proposed antenna has both main lobe and side lobe levels, it works as a bi-directional antenna. Due to unavailability of anechoic chamber, experimental results for radiation pattern of the fabricated antenna could not be obtained.

3.1.3. Gain

Figure 7 illustrates the simulated gain of the proposed antenna, with a peak gain value of 1.14 dB at the resonant frequency of 2.4 GHz, which is comparatively lower than the typical values.

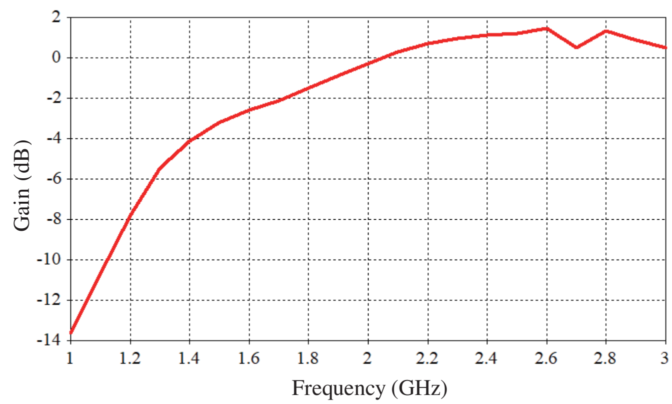


FIGURE 7. Realized gain of the proposed antenna.

3.1.4. Efficiency

The radiation efficiency is calculated in percentage in this paper as shown in Figure 8. The peak value of radiation efficiency is obtained as 73.35% at resonant frequency 2.4 GHz which is a quite good result.

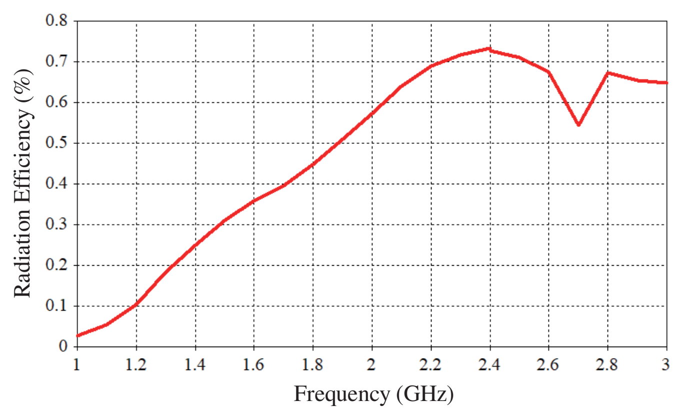


FIGURE 8. Radiation efficiency of the proposed antenna.

3.2. Implementation of the Proposed Antenna in IoT Based Home Automation System

For verifying the performance of the proposed antenna in IoT applications, it is essential to implement the antenna into an IoT based application. So, the fabricated antenna is attached to an IoT based home automation system shown in Figure 9. To do so, the built-in antenna in ESP8266 NodeMCU was replaced by the proposed antenna of this paper. For replacing the built-in antenna of ESP8266, it was cut in several places, then the fabricated antenna was soldered onto ESP8266 NodeMCU. Thus, the proposed antenna works as antenna of ESP8266 and performs in home automation system which verifies its compatibility in IoT based applications.

4. COMPARISON WITH THE EXISTING ANTENNAS

In this paper, a microstrip patch antenna which is featured with an inverse S-shaped meander line connected with rectangular box which helps in improving bandwidth and impedance matching is discussed. It also carries a parasitic patch and slotted partial ground to enhance bandwidth and return loss. The previous studies proposed various techniques of design such as L-shaped, S-shaped, circular structures, cage structure, and defective ground slots, which have their own advantages.

Table 2 presents a comparative analysis of the proposed antenna structure with the antennas reported in previous studies. From the comparison shown in Table 2, the proposed antenna has higher bandwidths than other existing antennas. Again, the

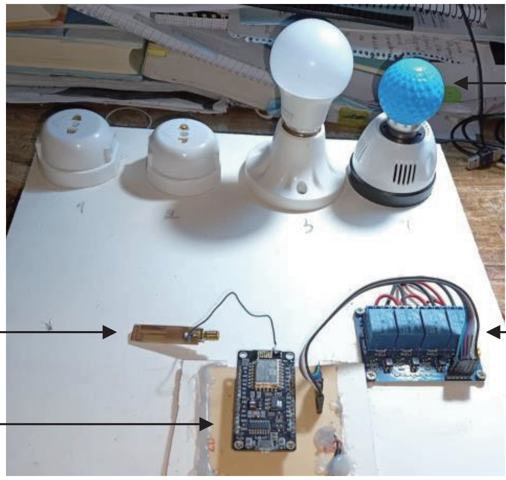


FIGURE 9. Experimental setup for IoT based home automation system incorporating proposed antenna.

TABLE 2. Comparative analysis of the proposed antenna model with the existing antenna models.

Ref.	Size (mm^2)	Antenna Type	Resonant Frequency (GHz)	Bandwidth (%)	Gain (dB)	Application	Comparison with the Proposed Antenna
[2]	15×90.86	Monopole Meander Line	2.4	4.00	2.00	WLAN	Lower bandwidth and larger size
[11]	70×50	Double-T Monopole	2.4	3.43	1.30	WLAN	Lower bandwidth and larger size
[13]	28×21	L-Shaped	2.4	5.83	2.09	IoT	Lower bandwidth and larger size
[17]	100×40	S-Shaped	2.4	3.30	Not Specified	WLAN	Lower bandwidth and larger size
[20]	75.7×75.7	Circular Slotted Patch	2.4	6.53	6.58	WBAN	Lower bandwidth and larger size
[25]	49×49	Cage Antenna	2.4	3.50	3.00	WLAN	Lower bandwidth and larger size
[26]	30×20	Planar MIMO	1.8	4.44	1.5	IoT	Lower bandwidth and larger size
			2.4	7.91	2.5		
			3.4	13.23	2.8		
			5.4	9.25	3.6		
[27]	52.3×128	MIMO Patch	2.4	8.00	2.56	WLAN	Lower bandwidth and larger size
[31]	10×19	Uniplanar Meandered	2.4	8.00	1.20	TD-LTE/WLAN	Lower bandwidth
This Work	**40×10**	**Meander Line with Defected Ground and Parasitic Patch**	**2.4**	**8.75**	**1.14**	**IoT**	**Small size with high bandwidth**

proposed design incorporates the meander line, partial ground, ground slots, and usage of parasitic patch, which has not been utilized yet in previous studies. This combination improves the impedance matching by providing smaller return losses. Though the proposed design has low gain compared to others, it is much more compact than many of other antenna designs.

5. CONCLUSION

A meandering shaped microstrip patch antenna for IoT applications is introduced in this work. The proposed antenna performs at 2.4 GHz (ISM band) with a bandwidth of 200 MHz. An FR-4 lossy material is used as the substrate to design the proposed antenna. It consists of a meander line which is connected with box shaped of rectangle, providing a compact size of $40 \times 10 \times 1.6\,\text{mm}^3$, better bandwidth, and perfect impedance matching. It also features the concept of defected ground and slotted parasitic patch to provide improved bandwidth and small return loss, indicating a vital contribution to the field of antenna construction in IoT applications. The antenna provides simulated return loss of -42.81 dB at 2.4 GHz with a bandwidth of 200 MHz (8.33%). It also provides a VSWR of 1.014 which indicates excellent impedance matching. The fabricated antenna is tested with LiteVNA and provides a return loss of -24.67 dB with a bandwidth of 210 MHz (8.75%) and a VSWR of 1.27, representing good impedance matching. Due to instrumental errors, small deviations occurred between the simulated and measured results. The antenna also provides a radiation efficiency of 73.35% with a gain of 1.14 dB. Finally, the proposed antenna is applied to an IoT based home automation system to verify its compatibility in IoT applications.

6. FUTURE WORK

- As FR-4 material has some drawbacks of lower high frequency performance, not suitable for Ultra-High Frequency (UHF) performance, limited thermal conductivity, and higher moisture absorption rate, textile or nanocomposite materials can be used as alternative substrates to address these challenges [46, 47].
- This type of application can also be implemented using a MIMO antenna. Since the proposed antenna features a defected ground for enhanced bandwidth and demonstrates good efficiency, future enhancements could focus on transforming it into a MIMO antenna [48].

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