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REGULAR ARTICLE

High-Gain Slit-Loaded Microstrip Patch Antenna with Defected Ground Structure for WLAN at 5.8 GHz

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This work proposes a high-gain slit-loaded microstrip patch antenna with defected ground structure (DGS) to be used for WLAN at 5.8 GHz. The antenna is built on an Arlon AD 410 substrate with a thickness of 1.6 mm and a relative permittivity of 4.1. The proposed configuration employs a modified rectangular patch with narrow slits, an elliptical defect and rectangular slot in the ground plane to enhance impedance matching and radiation performance. The simulated results indicate that the antenna resonates at 5.8 GHz with reflection coefficient (S_{11}) of – 57.95 dB and an impedance bandwidth of 520 MHz. The antenna also achieves a peak gain of 7.6 dBi and a maximum radiation efficiency of 92 %. It is observed that the proposed antenna offers a small-size structure and enhanced performance, and it can be applied in the WLAN in the 5.8 GHz band.

Keywords: Microstrip patch antenna, Slit loading, Defected ground structure, WLAN, 5.8 GHz, Impedance matching, Radiation efficiency, High gain.

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1. INTRODUCTION

As wireless communication technologies advance, there is an increasing demand for compact, low profile, and high-performance antennas capable of supporting high data rate transmissions. Currently, the 5.8 GHz band serves as the primary medium for transferring data in high-speed networks such as Wireless Local Area Networks (WLANs) [1]. At this band, antennas must exhibit sufficient bandwidth, good impedance matching, high radiation performance, and small form factor [2].

In such applications, Microstrip Patch Antennas (MPAs) have been highly embraced due to their low profile, light weight, fabrication easiness, and planar microwave circuit's compatibility. Nonetheless, traditional MPAs are in principle characterized by limited impedance bandwidth, moderate gain and sensitivity to geometrical parameters, which restricts their application in the modern wireless systems [2, 3]. Consequently, there have been massive research studies to enhance the bandwidth and radiation properties of microstrip antennas without increasing their physical complexity.

WLAN antennas in the 5-6 GHz frequency range normally have gains of around 5 dBi and impedance bandwidth of about 200-400 MHz, again depending on the design configuration [3, 4]. Some of the widely used techniques to enhance the impedance matching and bandwidth performance include slot/slit loading and defected ground structures (DGS). Slot/slit loading alters the distribution of current on the surface and raises the effective electrical length of the radiator so that resonance control can be better achieved without having to enlarge the physical size of the antenna [5]. In a similar manner, DGS alters the existing distribution of the ground plane that results in the enhanced impedance properties and the avoidance of unwanted surface waves [6, 7].

Irrespective of these advances, many reported designs are based on complicated feeding [3], multilayer configurations [8] or multiband operation [5, 9], which complicate fabrication and reduce their applicability to small and low-cost WLAN devices [5, 9-12]. Moreover, enhancement of bandwidth is in other instances at the cost of the impedance stability or radiation performance, which means a trade-off between important performance parameters of the antenna. Thus, the realization of a simple, compact and high gain antenna with balanced performance features is still a hard task.

A slit-loaded patch antenna with a defected ground structure, operating at 5.8 GHz, intended for WLAN, is

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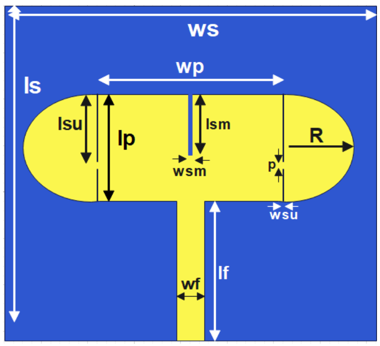
proposed in this work. The antenna is constructed on an Arlon AD 410 substrate. The upper side of the substrate contains a modified radiating patch antenna loaded with several thin slits and fed through a microstrip line. On the bottom side of the substrate is a defected ground plane with an elliptical ad rectangular slots to enhance impedance matching and radiation performance. Extensive simulations are then carried out to examine the effects of some important geometrical parameters on the antenna characteristics. The proposed design offers a compact structure, high gain, better impedance matching, reasonable bandwidth, and stable radiation characteristics; hence, it can be effectively used in the WLAN.

The rest of the paper is structured in the following way: Section 2 gives a description of the antenna design and geometry. The results and discussion are provided in Section 3. Section 4 makes a comparison of the proposed antenna and the existing designs. Lastly, Section 5 makes a conclusion to the paper.

2. ANTENNA DESIGN AND GEOMETRY

The proposed antenna is a defected ground structure (DGS)-based, microstrip line-fed, slit-loaded patch antenna specifically engineered for the 5.8 GHz WLAN band. It is fabricated on an Arlon AD410 substrate, featuring a relative permittivity (ε_r) of 4.1 and a thickness of 1.6 mm. This material choice provides a strategic compromise between a compact physical footprint, dielectric stability, and high radiation performance. The total substrate dimensions are optimized at 40 mm × 36 mm.



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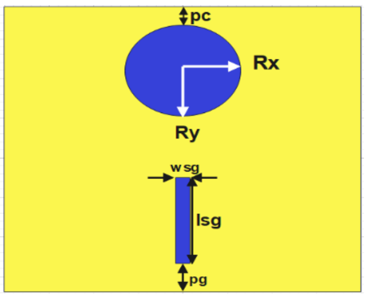

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Fig. 1 – Geometry of the proposed antenna: (a) top view, (b) bottom view

The geometry of the optimized antenna, as illustrated in Fig. 1, consists of a modified radiating patch on the top surface and a defected ground plane on the bottom. The design evolved through several iterative stages. Initially, it began as a standard rectangular patch (*lp* × *wp*) fed by a microstrip line (*lf* × *wf*). In the subsequent stage, a thin rectangular slit (*lsm* × *wsm*) was embedded into the front of the main patch. This was followed by the addition of two rounded patches connected to the main structure via very small strips (*p* × *wsu*). Despite these modifications, the initial S_{11} performance remained above – 10 dB, indicating poor impedance matching and a lack of functional bandwidth as shown in Fig. 2. However, as noted from Fig. 3 and Fig. 4, the gain and radiation efficiency improved in these stages (stage-1 – stage-3).

The breakthrough in performance occurred during the final stages of development. By incorporating an elliptical DGS (stage-4) into the upper portion of the ground plane and a rectangular DGS (stage-5) into the lower portion, the current distribution was significantly altered. These ground-plane perturbations, combined with the slit loading on the patch, enhanced the impedance matching and broadened the bandwidth. The slots effectively increased the antenna's electrical length without increasing its physical size, while the rounded geometry of the patch stabilized the fringing fields at the patch edges for consistent radiation characteristics.

Ultimately, the synergy between the patch perturbations and the defected ground structure allows the antenna to achieve superior impedance bandwidth, high gain, and excellent radiation efficiency. By altering the return current path and the analogous reactive behavior, the design successfully meets the rigorous demands of the target frequency band. The optimized design performance in terms of S_{11}, gain, and radiation efficiency is presented in Fig. 2, Fig. 3, and Fig. 4, while its optimized geometrical parameters are summarized in Table 1.

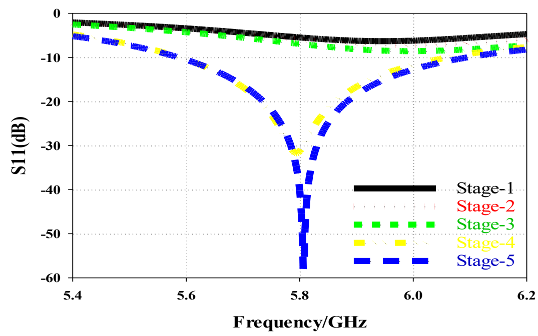

Fig. 2 – Simulated S_{11} performance for the proposed antenna across different design stages

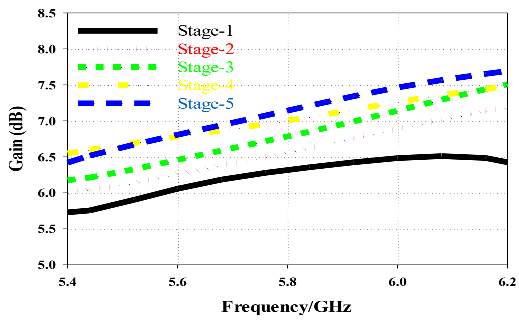

Fig. 3 – Simulated gain performance for the proposed antenna across different design stages

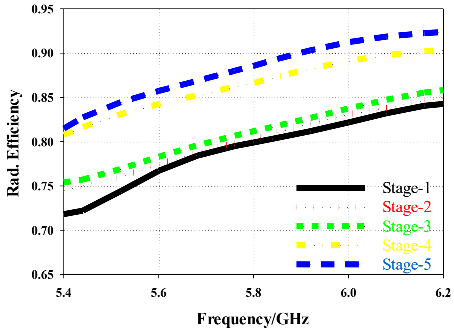

Fig. 4 – Simulated radiation efficiency performance for the proposed antenna across different design stages

Table 1 – Optimized geometrical parameters of the proposed antenna

Parameter	Value (mm)	Parameter	Value (mm)
ws	40	*wp*	20
ls	36	*lp*	11.5
h	1.6	*R*	8.527
wf	2.727	*lf*	15
wsu	0.1	*P*	0.6
wsm	0.4	*lsm*	6.5
pg	1	*lsg*	11
pc	0.7	*wsg*	1
Rx	6.8	*Ry*	6.5
lsu	7.3		

3. RESULTS AND DISCUSSION

CST Microwave Studio was used to test the electromagnetic behavior of the proposed antenna. The simulations focused on the reflection coefficient (S_{11}), Voltage Standing Wave Ratio (VSWR), input impedance, surface current distribution, and gain and radiation efficiency. Furthermore, an extensive parametric analysis for some effective dimensions was carried out to adjust the design and obtain the optimal performance. The optimized design resonates at 5.8 GHz with an impedance bandwidth of 520 MHz, a minimum S_{11} of – 57.95 dB, a VSWR of 1.0025, a peak gain of 7.6 dBi, and a radiation efficiency of 92 %.

3.1 Reflection Coefficient and Bandwidth

The simulated reflection coefficient (S_{11}) of the proposed antenna is shown in Fig. 5. At 5.8 GHz, a strong resonance is seen with the lowest value of S_{11} of around – 57.95 dB. Such a result means that the impedance matching is very strong in the desired operating frequency. The – 10 dB simulated bandwidth is 520 MHz, extending from 5.58 GHz to 6.10 GHz, which is sufficient for WLAN usage.

3.2 VSWR

Fig. 6 shows the simulated VSWR performance. A minimum VSWR value of 1.0025 is achieved at the resonant frequency, which is very close to the optimal value of unity. This low value of VSWR proves that the antenna is highly coupled with the feeding structure at 5.8 GHz. The VSWR is less than 2 across the operating frequency range, which confirms that there is an acceptable impedance matching across the operating frequency range.

3.3 Input Impedance

Fig. 7 represents the simulated input impedance of the antenna throughout the operational band. The magnitude of the input impedance is 53.6 Ω, which is very close to the theoretical value of 50 Ω. This is the reason why the reflection coefficient is very low and the VSWR is almost close to unity at the resonant frequency.

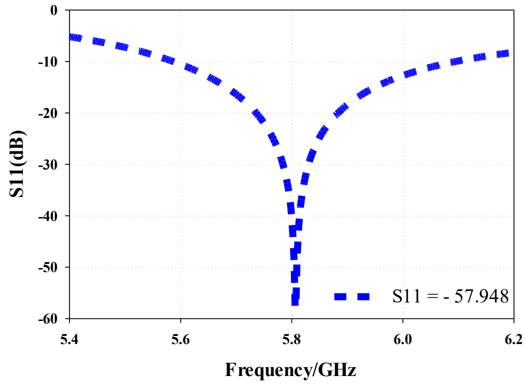

Fig. 5 – Simulated S_{11} performance of the optimized design

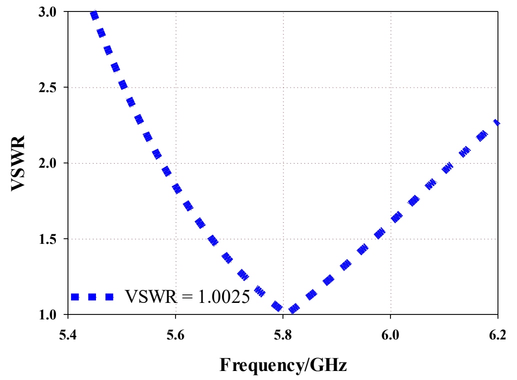

Fig. 6 – Simulated VSWR performance of the optimized design

3.4 Surface Current Distribution

Fig. 8 illustrates that the current distribution at 5.8 GHz concentrates in the feed line, patch edges, and around slots' edges. This implies that slots and slits are used to effectively alter the existing current paths and enhance the performance. The defected ground structures also perturb the return current and hence improving the impedance matching behavior and the radiation gain.

3.5 Gain and Radiation Efficiency

The 3D radiation pattern of the proposed antenna at 5.8 GHz is shown in Fig. 9. As noted, the gain achieved at the resonant frequency is 7.15 dBi and the radiation efficiency is 88.6 %. Fig. 10 presents the gain and radiation efficiency across the operational band. From this figure, we can see that the gain varies from 6.8 dBi at the lower side of the band to 7.6 dBi at the upper side of the operational band. Similarly, the radiation efficiency varies between 85.4 % to 92 %. These results confirm that the antenna radiates efficiently within the desired band.

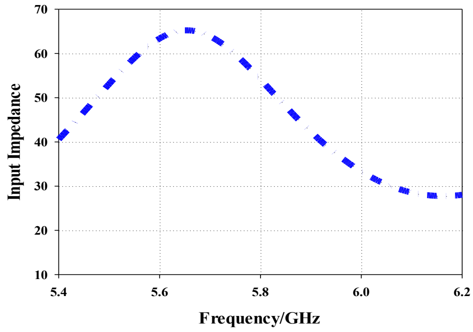

Fig. 7 – Input impedance of the proposed design throughout the operational band

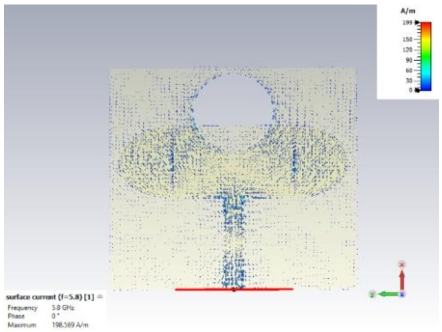

Fig. 8 – Surface current distribution at 5.8 GHz

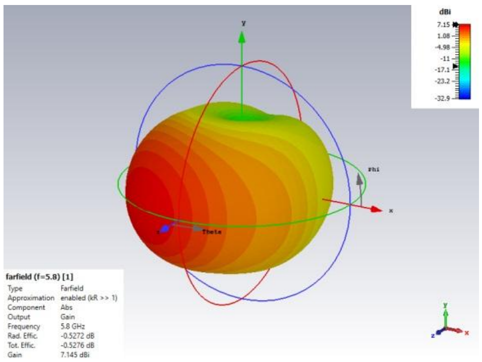

Fig. 9 – 3D radiation pattern of the optimized design at 5.8 GHz

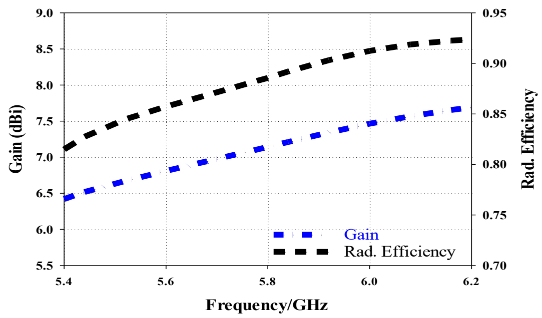

Fig. 10 – Gain and radiation efficiency vs frequency of the optimized design

3.6 Parametric Analysis

To examine the effects of some key geometrical parameters on the antenna performance i.e., radii of the elliptical slot on the ground (R_x, R_y) and feed length (*lf*), simulations were carried out at different values for these parameters. The relevant findings are presented in Fig. 11, Fig. 12 and Fig. 13.

The effects of the feed length (*lf*) on the S_{11} performance are presented in Fig. 11. Here, varying the value of *lf* causes a significant deviation of the resonant frequency as well as the value of S_{11}. Increasing the value of lf above the optimal value shifts the resonant frequency below the 5.8 GHz and reduces the S_{11}. Oppositely, decreasing the feed length below the optimal value leads to shifting the resonance frequency above the 5.8 GHz with deteriorating the value of S_{11}. The best response is achieved at *lf* = 15 mm where the antenna resonates with the strongest matching at the desired 5.8 GHz frequency. At this optimal point, the S_{11} value is – 57.95 dB with wider bandwidth of 520 MHz.

The parameter R_x has a strong impact on S_{11} performance as shown in Fig. 12. The optimal value for this parameter is 6.5 mm as indicated from the solid black curve in Fig. 12, where the resonance is exactly at the required frequency of 5.8 GHz and with the best matching as indicated by the low value of S_{11}. Reducing the value of R_x to 6 mm shifts the resonance up to near 5.9 GHz with deteriorating the S_{11} value. On the other hand, increasing the value of R_x to 7 mm moves the resonance down to near 5.7 GHz with deteriorating the S_{11} performance.

Finally, the influences of varying R_y on the S_{11} performance are illustrated in Fig. 13. The variation in this parameter has strong effects on the return loss with a noticeable shifting of the resonance frequency below and above the 5.8 GHz. Optimal responses is achieved at 6.8 mm, and the reflection coefficient value is at its lowest. This establishes that the defected ground plays a critical role in the optimization of resonance and impedance matching by altering the current of the return path underneath the radiator.

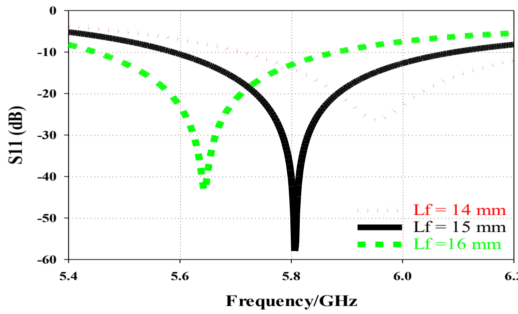

Fig. 11 – Effects of varying *lf* on the S_{11} performance

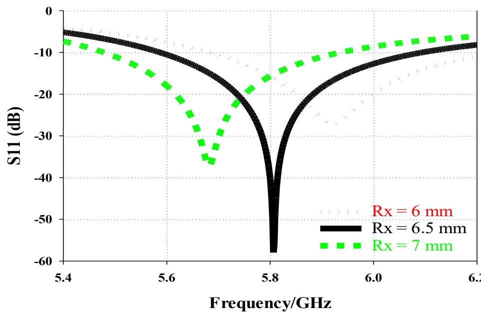

Fig. 12 – Effects of varying R_x on the S_{11} performance

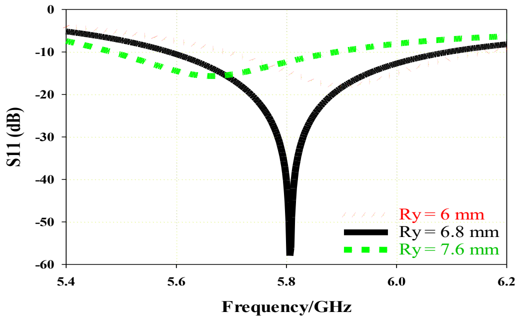

Fig. 13 – Effects of varying R_y on the S_{11} performance

4. COMPARISON WITH EXISTING LITERATURE

Table 2 summarizes a comparison of the proposed antenna with some recently reported designs operating in the 5.8 GHz band. The comparison includes antenna size, S_{11}, gain, bandwidth, and radiation efficiency.

It is seen that the proposed antenna has a reflection coefficient of – 57.95 dB, which is much better than all other reported designs, and is an indicator of very good impedance matching. The gain of the proposed antenna is also higher than the gain of all other designs reported in [5, 9, 10, 12]. In addition, the proposed design achieves better bandwidth than those in [5, 9]. The proposed design proves its superiority to the designs in Table 2 although it is slightly larger than the designs reported in [5, 9]. The proposed design is generally a good balance between small size, high gain, wide bandwidth, and great impedance matching and is suitable for 5.8 GHz WLAN applications.

Table 2 – Comparison of the proposed antenna with published works

Ref.	[5]	[9]	[10]	[12]	This work
Sub.	FR-4	Rogers AD 225C	Kapton	FR-4	Arlon AD410
Size (mm³)	36 × 37 × 1.6	30 × 30 × 1.56	55 × 40 × 0.125	35 × 50 × 1.6	40 × 36 × 1.6
f_0 (GHz)	3.45/5.9	3.5/5.8	4.35 (center fre.)	5.8	5.8
S_{11} (dB)	– 22.9	– 22.9 @5.9	N/A	– 26	– 57.95
Gain (dBi)	0.537 @5.9	4.62 @5.8	2.5-5.9	3.93	7.6
BW (GHz)	0.220 @5.9	~ 0.240	5.18	~0.550	0.520
Rad. Eff. (%)	45	N/A	60-90	86.2	92

5. CONCLUSION

This work introduced a compact high gain slit-loaded patch antenna with a defected ground structure for 5.8 GHz WLAN applications. The antenna merges patch modifications together with ground-plane perturbation in order to obtain better impedance matching, high gain, good radiation performance, and reasonable bandwidth. The optimized antenna achieved a reflection coefficient of – 57.95 dB, an impedance bandwidth of 520 MHz, a peak gain of 7.6 dBi, and a maximum radiation efficiency of 92 %. These results indicate that the proposed design has a good impedance matching and good radiation characteristics in the intended band. Overall, the proposed antenna is reasonably compact, simple, and has good characteristics, which make it a good candidate for WLAN applications at 5.8 GHz.

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Мікросмужкова патч-антена з високим коефіцієнтом підсилення та щілинним навантаженням з дефектною заземлювальною структурою для WLAN на частоті 5,8 ГГц

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Запропонована конструкція висококоефіцієнтної мікросмужкової патч-антени з щілинним навантаженням та дефектною заземлювальною структурою (DGS) для використання в WLAN на частоті 5,8 ГГц. Антена побудована на підкладці Arlon AD 410 товщиною 1,6 мм та відносною діелектричною проникністю 4,1. Конфігурація у вигляді модифікованого прямокутного патчу з вузькими щілинами, еліптичним дефектом та прямокутною щілиною в заземлювальній площині для покращення узгодження імпедансу та характеристик випромінювання. Результати моделювання показують, що антена резонує на частоті 5,8 ГГц з коефіцієнтом відбиття (*S*11) – 57,95 дБ та смугою пропускання імпедансу 520 МГц. Антена також досягає пікового коефіцієнта підсилення 7,6 дБі та максимальної ефективності випромінювання 92 %. Зазначено, що запропонована антена має малогабаритну структуру та покращені характеристики, і її можна застосовувати в WLAN у діапазоні 5,8 ГГц.

Ключові слова: Мікросмужкова патч-антена, Щілинне навантаження, Дефектна структура заземлення, WLAN, 5,8 ГГц, Узгодження імпедансу, Ефективність випромінювання, Високий коефіцієнт підсилення.