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A Compact F-Slot-Enhanced PIFA Design for Dual-Band Bluetooth and WLAN Applications

Yahya Entiefa Mansour [1*], Abduladeem Beltayib [2], Allafi Omran[3]
[1,2,3] Electrical Engineering Department College of Technical Sciences, Bani Walid, Libya

تصميم هوائي *PIFA* ثنائي النطاق مضغوط مع فتحة *F* محسّنة لتطبيقات البلوتوث وشبكات *WLAN*

يحيى انتيفة منصور [1*]، عبد العظيم بالطيب [2]، اللافي عمران [3]
[1، 2، 3] قسم الهندسة الكهربائية، كلية العلوم التقنية، بني وليد، ليبيا

[*]Corresponding author: yahiqm22@gmail.com

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Abstract:
A dual-band PIFA operating at 2.4 and 5.2 GHz is proposed and designed in this paper for wireless communication applications. The presented antenna design integrates multiple resonant paths by utilizing slots and a shorting pin, allowing for dual-band operation while maintaining a low-profile shape factor suitable for modern mobile and embedded devices. This antenna is commonly utilized for Wi-Fi, which can provide coverage in the band range from 2.4 GHz up to 5.2 GHz, which is used for wireless networking technology. Based on this requirement, a dual-band air-inverted F antenna is proposed. The proposed structure is very small in size, and due ground plane at the backside, it has low back lob radiation. All essential performance parameters, such as return loss, bandwidth, radiation pattern, and efficiency of this design, were investigated through a well-known full-wave simulator HFSS package. Simulation results indicate that the performance parameters have promising behavior for both frequency bands. Due to its dual-band functionality, size, low back radiation, and low back radiation, it is a good candidate for wireless networks.

Keywords: Dual-band antenna; PIFA; WLAN; Slot-loaded antenna.

الملخص
في هذا البحث تم تصميم هوائي PIFA ثنائي النطاق يعمل عند الترددين 2.4 GHz و 5 GHz ومصمم لأغراض الاتصالات اللاسلكية. يدمج تصميم الهوائي المقدم مسارات رنين متعددة باستخدام الفتحات (Slots) ودبوس التقصير، مما يتيح التشغيل ثنائي النطاق مع الحفاظ على حجم صغير مناسب للأجهزة المحمولة والأنظمة المدمجة الحديثة. يُستخدم هذا الهوائي غالباً في تطبيقات الواي فاي (Wi-Fi) التي توفر تغطية ضمن مدى التردد من 2.4 GHz حتى 5 GHz المستخدمة في تقنيات الشبكات اللاسلكية. وبناءً على هذا المطلب، تم اقتراح هوائي PIFA مقلوب ثنائي النطاق يمتاز الهيكل المقترح بصغر حجمه، كما أن وجود مستوى التأريض (Ground Plane) في الجهة الخلفية يقلل من الإشعاع الخلفي. تم تحليل جميع معايير الأداء الأساسية مثل فقد الانعكاس (Return Loss)، عرض الحزمة (Bandwidth)، نمط الإشعاع (Radiation Pattern)، والكفاءة (Efficiency) باستخدام برنامج المحاكاة المعروف HFSS المعتمد على طريقة الموجات الكاملة. تشير نتائج المحاكاة إلى أن معايير الأداء تُظهر اداءً وجيدا عند كلا الترددين. وبفضل خصائصه كالعمل في تردد ثنائي النطاق، وصغر حجمه، وانخفاض الإشعاع الخلفي، فإنه يُعد مرشحاً جيداً لتطبيقات الشبكات اللاسلكية.

الكلمات المفتاحية: هوائي ثنائي التردد، PIFA، الشبكات اللاسلكية، نمط الاشعاع.

Introduction

Due to the rapid growth of wireless communication systems, there is an increasing demand for small, practical, multiband antennas that can support several wireless communication system standards. The planar Inverted F Antenna (PIFA) is one of the antenna types that attracts the most attention because of its low profile, exceptional performance in portable and embedded devices, and ease of fabrication. Wireless Local Area Networks (WLAN) are often implemented in modern communication devices using the 2.4 GHz and 5 GHz frequency bands. For compactness and economy, it is crucial to design a single antenna that works effectively at both frequencies [1]. Furthermore, there has always been a sustained interest in wideband antennas for mobile antenna applications. Numerous analogous printed flat-plate antenna designs have recently been proven for real-world WLAN performance in the 2.4 and 5GHz bands [2].

The design and fabrication of dual-band PIFA antennas for WLAN applications have been the focus of many investigations. By adding a slot and shorting pin, a small dual-band PIFA was generated in [3] that operated effectively at 2.4/5.2 GHz with good isolation and return loss. While [4] proposed a folded PIFA with an L-shaped slot for enhancing dual-band resonance, [5] utilized a modified ground plane construction to increase bandwidth and minimize the antenna area. In order to facilitate adaptive wireless applications, multiband and configurable PIFA designs have also been studied [6], [7].

planar inverted-F antennae (PIFA) could be used to cover 5G ultrawideband MIMO antenna by combining two antennas structure, these two antennas characterized by T-shaped slot. This can lead to achieving high bandwidth efficiency.to cover New Radio 5G NR n77 to n79 and long-term evolution LTE band, the shorting stub is used to minimize the coupling between adjacent radiators, in this way, current flows to the reflector rather than flowing to a passive point such that non-resonant PIFA [8].

Recent studies have also shown the importance of advanced antenna structures for next-generation wireless systems. High-gain leaky-wave antennas, such as those presented in [9], demonstrate how periodic slot loading and optimized waveguide configurations can significantly enhance radiation characteristics, particularly for millimeter-wave applications. Similarly, research in UAV-assisted wireless networks highlights the critical role of efficient antenna design in ensuring reliable connectivity and fair load distribution across multi-UAV systems [10]. These developments emphasize the continuous need for improved dual-band and multiband antenna structures, reinforcing the motivation for designing an efficient dual-band PIFA suitable for modern WLAN applications.

In this paper, the dual-band technique using a PIFA antenna has been designed. In general, the standard antenna formulas have been used in design to get the resonance frequency. In order to have the dual-band operation, the slots have been etched on the arms of the antenna to give an F-shape, following the current trace on the antenna's main body and the two arms. the antenna has been investigated with acceptable gain, low side lobe level, and a low cross-polarization in the interested frequencies. The radiation pattern and all the simulation results were done using HFSS.

Antenna Design

A- Antenna Configuration Without Slot.

A two-dimensional (2D) Planar Inverted F Antenna (PIFA) is designed on RT/Duroid 5880 substrate, with a dielectric constant of 2.2 and a loss tangent of 0.0009, and its thickness is 0.5 mm. The PIFA design used to form the suggested antenna shape. We employed a single metal patch to produce a 2.4 GHz WLAN antenna. In Figure 1, the structure of PIFA antenna is shown. The proposed structure consists of two main parts, shorting pin and feeding pin. In shorting pin, the antenna length is dropped by half a wavelength, where its length is λ/4 to fit small devices. As shown in Figure 1, the total size of the proposed antenna has a volume of 40 × 47 × 0.5 mm³.

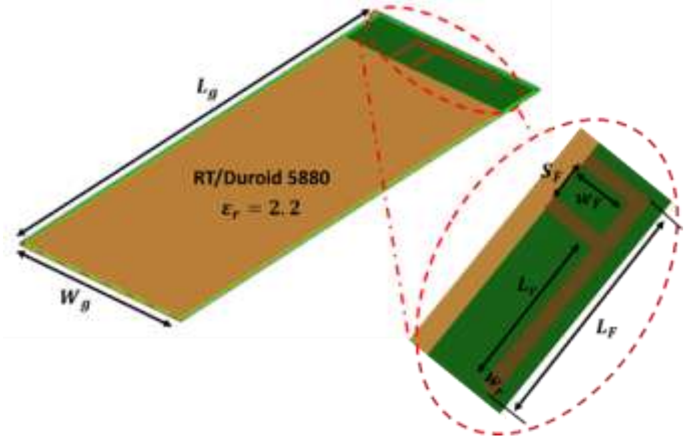

Figure 1. The geometry of the proposed Planar Inverted F Antenna PIFA structure.

Table 1 indicates all the dimensions of the antenna. All the antenna dimensions are calculated based on the resonance frequency of 2.4 GHz, which is compatible with the WLAN application.

Table 1 . antenna dimensions

parameter	Value(mm)
L_g	47
W_g	40
W_f	6.2
L_r	0.182
L_f	25.6
W_r	1.5
S_f	4.4

As shown in the antenna structure in Figure1, the antenna is fed by stripline pin connected to the bottom of the antenna structure attached to the ground plane. In order to adjust the resonant frequency and impedance bandwidth, the ground plane at the bottom side should be modified. Figure 2 shows the Return Loss (S_{11}) plot of the proposed antenna, simulated using ANSYS HFSS 2025 R2, which comes with introduces "An–sys Engineering Copilot", an AI-driven assistant built into ANSYS products (including HFSS), with a resonance at 2.4 GHz where the return loss is less than-20 dB, and the maximum realized gain is 4.28 dBi.

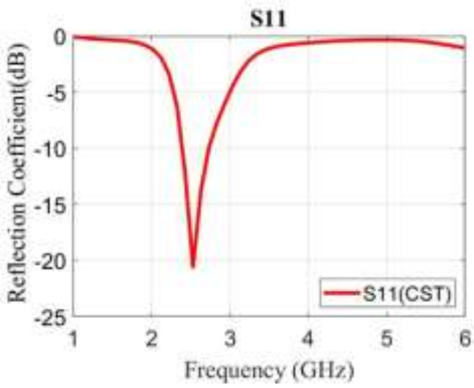

Figure 2. Simulated reflection of the proposed antenna S11

Figure 3 illustrates a 3D antenna gain. The total gain is shown as a function of phi and theta, with a maximum value of approximately 4.28 dB, this value is regarded as normal gain as comparable to that of other microstrip antennas, since microstrip antennas are known to have the drawback of low gain in trade-off with antenna size.

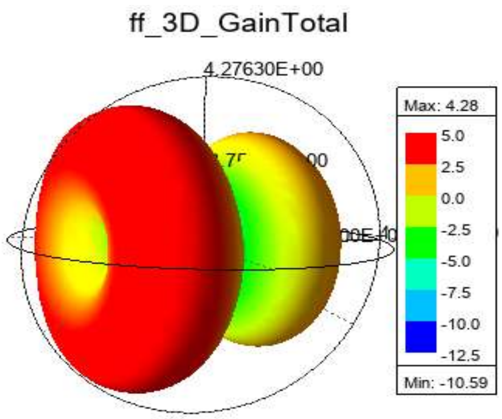

Figure 3. antenna Gain

The proposed PIFA antenna's three-dimensional radiation pattern is shown in Figure 4. As is typical of compact monopole-type structures, the antenna's radiation characteristic is mainly omnidirectional. Effective radiation away from the ground plane is indicated by the main lobe's forward orientation, which is normal to the radiating patch. Low back-lobe levels result from the ground plane acting as an effective reflector, which greatly suppresses backward radiation. The radiation envelope demonstrates a continuous, smooth shape without of sharp nulls, indicating stable performance throughout the antenna surface. The radiation intensity distribution shows that the antenna can provide a wide coverage pattern, which makes it appropriate for embedded and handheld WLAN applications where orientation changes while in use. All things considered, the pattern is consistent with the expected behavior of PIFA structures, offering stable directional characteristics and balanced gain throughout the operating bands [11].

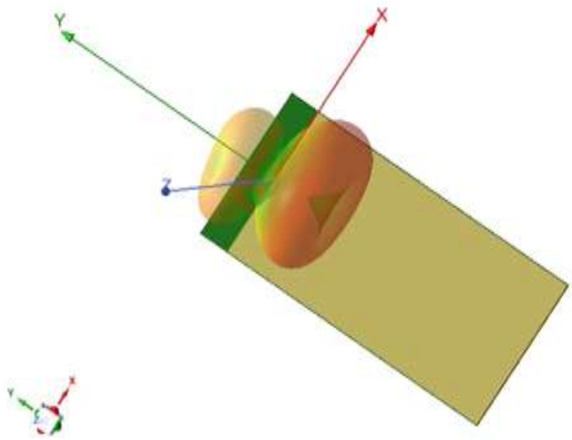

Figure 4. 3D radiation pattern of the proposed PIFA antenna showing the forward main lobe and reduced back radiation

B. Antenna Configuration with Slot

Same the structure of PIFA antenna with slot in the F-shape as shown in Figure 5 The total size of the proposed antenna has the volume of 40 × 47 × 0.5 mm3. Three slots are etched on the both ends of the latter F the main body of it. These slots are the reason to generate an additional resonance at 5 GHz. It was carefully designed and optimized through parametric sweeping to achieve a well-defined resonant frequency at 5GHz.

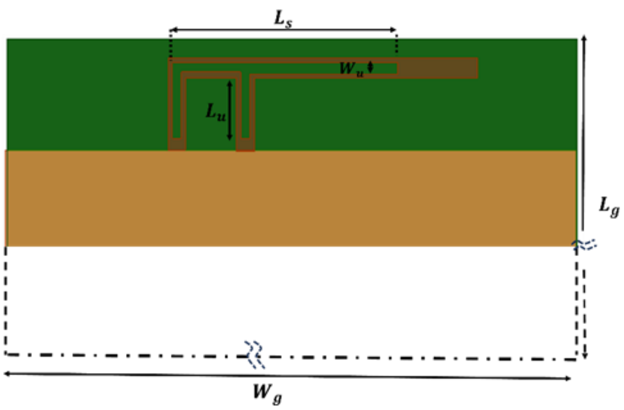

Figure 5. The geometry of the proposed Planar Inverted F Antenna PIFA structure with slot.

Figure 6 displays the proposed antenna return loss, where there are two frequencies at 2.4 and 5 GHz. The First resonance at 2.40 GHz with a return loss of –28 dB, with this value, antenna performance is at acceptable levels, which is commonly used for Wi-Fi (IEEE 802.11b/g/n), Bluetooth, and Zigbee. On the other hand, 5 GHz with a return loss of -24.51 is the second goal for our design. It is a complicated relationship between antenna length, slot size, and ground plane. All are governed by tradeoffs in their performance, such that decreasing the size of the ground plane (which plays the role of reflector) will affect antenna Gain; consequently, the S11 will also be decreased. At 5Ghz with a return loss of –24.51 dB, where this band is mainly used for Wi-Fi (IEEE 802.11a/n/ac) applications.

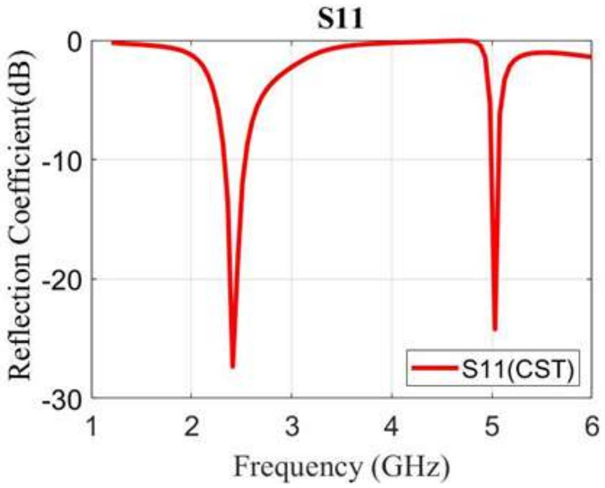

Figure 6. Simulated reflection of the proposed antenna with slot

The surface current distribution (J_{surf}) on PIFA antenna is shown in Figure 7, the minimum and maximum current could be distinguished by colour (Blue for lower currents and red for higher currents), this antenna has a maximum surface current equal 53 A/m. The most of the current flows are on the antenna edges. where it is clear that the Higher current concentration is seen around bends and corners of the trace.

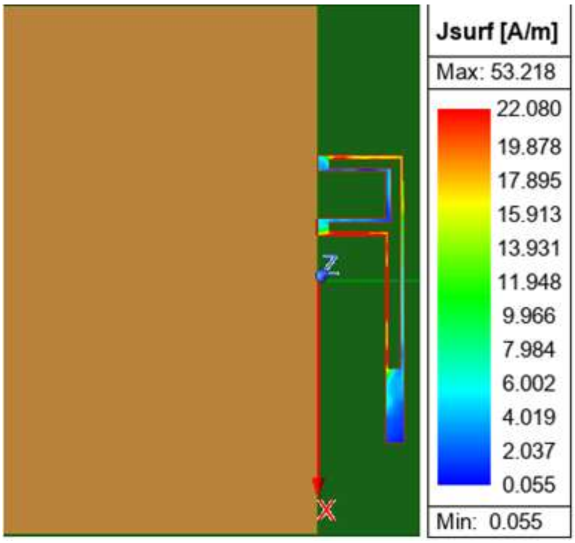

Figure 7. View the surface current distribution of the proposed design slots.

This suggests that the antenna is operating near resonant frequency, where current reaches peak values. The surface current pattern has a significant role in indicating how the antenna resonates and radiates: where High current around the feeding point confirms that power is being injected there.

A 3D Antenna Gain has been illustrated in the Figure. 8. This is the total gain depicted as a function of phi and theta, total gain with a maximum value of around 4.38 dB. This value is considered as normal gain as much as other microstrip antennas have, as known microstrip antenna has a reputation for the disadvantage of low gain in trade off with antenna size. The gain pattern comes in an asymmetric shape with the forward gain shaded in red. The backside lobes are in the range of zero dB to -7.5 dB, which is considered a low sidelobe level. As a result, the PIFA antenna radiates as an omnidirectional lobe, and this 3D polar plot of antenna gain visualizes how efficiently the antenna radiates energy in a specific direction.

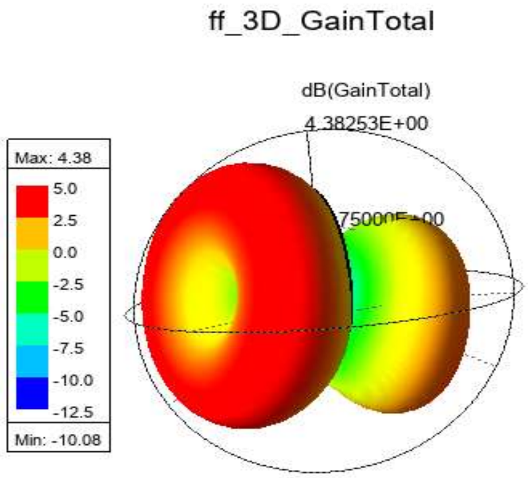

Figure 8. Antenna Gain of proposed design slots.

Conclusion

This paper effectively designs and investigates a compact dual-band Planar Inverted-F Antenna (PIFA) optimized for WLAN applications at 2.4 GHz and 5 GHz. The antenna's shape maintains a low-profile structure suitable for modern portable and embedded wireless devices while enabling dual-resonance behavior through the use of precisely etched slots and a shorting pin. The proposed layout shows excellent impedance matching at both operating bands, with return losses of –28 dB at 2.4 GHz and –24.5 dB at 5 GHz, according to simulation results obtained using ANSYS HFSS. In line with typical microstrip-based compact antennas, the antenna exhibits a stable radiation pattern with low back-lobe radiation and a realized gain of about 4.45 dB. The distribution of surface current confirms that both frequency bands exhibit appropriate resonance behavior. The proposed PIFA antenna is a suitable choice for integration into WLAN-capable devices that support IEEE 802.11b/g/n and 802.11a/n/ac standards because of its dual-band functionality, small size, low-profile configuration, and satisfactory gain performance. Additionally, the design methodology offers a basis for additional optimization in the direction of reconfigurable or multi-band wireless systems.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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