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Study and Design Multiband MPA Antenna for Smart Phones

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ABSTRACT

Modern wireless communication systems require compact multiband antennas that can operate efficiently over several frequency ranges used in mobile devices. However, conventional microstrip patch antennas often suffer from narrow bandwidth and limited gain, which restrict their use in multiband applications. This work presents the design and simulation of a compact slotted microstrip patch antenna intended for Wi-Fi, WLAN, WiMAX, and IMT applications. The antenna is designed on an FR-4 substrate and improved using rectangular slots and a partially reduced ground plane to enhance bandwidth and radiation characteristics. The proposed antenna is modeled and simulated using CST Microwave Studio 2019, and its performance is evaluated in terms of return loss, gain, directivity, VSWR, and surface current distribution. Simulation results show that the antenna operates effectively within the 2.9–7.6 GHz band, achieving resonant frequencies at 2.8 GHz, 3.80 GHz, and 4.61 GHz with a maximum bandwidth of 7.40 GHz. The design also provides a gain of up to 8.7 dB and maintains a VSWR below 2 across all operating bands. These results indicate that the proposed multiband slotted microstrip antenna is a strong candidate for integration into modern mobile and wireless communication systems.

دراسة وتصميم هوائي شريطي متعدد النطاقات للهاتف الذكي

جلال فال[1،*]، ناصر ابوهمود[1]، علي عبدالقادر[1]

الملخص

تتطلب أنظمة الاتصالات اللاسلكية الحديثة هوائيات مدمجة متعددة النطاقات، قادرة على العمل بكفاءة عبر نطاقات تردد متعددة تُستخدم في الأجهزة المحمولة. ومع ذلك، غالبًا ما تعاني هوائيات الرقعة الشريطية الدقيقة التقليدية من ضيق النطاق الترددي ومحدودية الكسب، مما يحد من استخدامها في التطبيقات متعددة النطاقات. يقدم هذا العمل تصميمًا ومحاكاة لهوائي رقعة شريطية دقيقة مشقوقة ومدمج، مُصمم لتطبيقات **Wi-Fi** و**WLAN** و**WiMAX** و**IMT**. صُمم الهوائي على ركيزة **FR-4**، وتم تحسينه باستخدام فتحات مستطيلة ومستوى أرضي مُصغّر جزئيًا لتحسين خصائص النطاق الترددي والإشعاع. تمت نمذجة الهوائي المقترح ومحاكاته باستخدام برنامج **CST Microwave Studio 2019**، وتم تقييم أدائه من حيث خسارة العودة، والكسب، والاتجاهية، ونسبة الموجة الدائمة المتغيرة (**VSWR**)، وتوزيع التيار السطحي. تُظهر نتائج المحاكاة أن الهوائي يعمل بفعالية ضمن النطاق الترددي2.9 - 7.6 جيجاهرتز، محققًا ترددات رنينية عند 2.8 جيجا هرتز، و3.8 جيجا هرتز، و4.61 جيجا هرتز، مع عرض نطاق ترددي أقصى يبلغ 7.4 جيجاهرتز. كما يوفر التصميم كسبًا يصل إلى 8.7 ديسيبل، ويحافظ على نسبة موجة ثابتة للجهد (**VSWR**) أقل من 2 في جميع نطاقات التشغيل. تشير هذه النتائج إلى أن هوائي الشريط الصغير متعدد النطاقات المقترح ذو الفتحات يُعدّ مرشحًا قويًا للدمج في أنظمة الاتصالات المتنقلة واللاسلكية الحديثة.

الكلمات المفتاحية

هوائي شريطي مشقوق
برنامج محاكاة المجال الكهرومغناطيسي
ركيزة شائعة الاستخدام *FR-4*
نظام الاتصالات المتنقلة الدولي

Introduction

Wireless communication has become an essential part of modern life, with applications ranging from mobile phones and Wi-Fi systems to intelligent transportation and emerging smart devices[2,13]. As communication standards continue to evolve, wireless systems increasingly rely on antennas that can operate over multiple frequency bands while maintaining compact size, low cost, and acceptable radiation performance [3,5]. Microstrip patch antennas (MPAs) are widely used in such applications due to their light weight, simple structure, ease of fabrication, and compatibility with printed circuit technology [1,10]. Despite these advantages, conventional MPAs suffer from inherent limitations, including narrow bandwidth [17,18], single-band operation, and relatively low gain [1]. These limitations restrict their use in devices that require multiband operation across several wireless standards such as Wi-Fi, WLAN, WiMAX and IMT [5,6]. Therefore, improving the bandwidth and multiband capabilities of MPAs has become an important research focus in recent antenna design studies [4,5,7]. A variety of techniques have been proposed to enhance the performance of microstrip patch

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antennas, including the use of slots, modified patch geometries, defected ground structures (DGS) [8,16], and partial ground planes. Among these methods, slot incorporation has proven effective in enabling multiband operation and improving impedance matching without significantly increasing the antenna's overall size [17-22].

The design principles of microstrip antennas were established through classic works. Their initial designs were limited to operating on a single frequency. Researchers focused on improving performance to meet the needs of mobile communications.

A significant development in multi-band antenna design is the use of geometric modifications such as aperture cutting. Roy and A. Dutta (2021)[1] also Performance Enhancement of MPA Using U-Slot for Wave Applications, which improved gain and directionality.Using slits in the ground surface has emerged as an effective method for increasing bandwidth and antenna gain. Kumar and P. S. Rani (2022)[2] studied the performance of rectangular slits in the ground surface of a 2.4 GHz antenna. The study demonstrated a significant improvement in return loss and an increase in gain. Gupta & N. Sharma (2021)[3] Slot introduced in ground plane and colleagues presented a rectangular double-loop antenna using a sloted ground structure, but its limitations in reconfiguration and inability to adapt to multiple bands weaken its efficiency for smart phones. Raj & A. Singh (2020) [6] Design of Slotted Patch Antenna with DGS for Multiband and relatively complex structure.

Table 1: results obtained from some previous studies and the current study.

Study	Design Approach	Key Results	Research Gap / Limitation
Roy and A. Dutta (2021)	U-Slot slotted rectangular patch	Enhancement of Gain and directivity	Limited number of bands
Kumar & P. S. Rani (2022)	Ground slot microstrip antenna	Improvement in return loss and an increase in gain.	Large antenna size, not suitable for compact smartphone integration
Gupta & N. Sharma (2021)	Slot introduced in ground plane	Improved return loss and gain	Focused mainly on gain improvement without significant bandwidth enhancement
Raj & A. Singh (2020)	Rectangular- with DGS (Defected Ground Structure)	Bandwidth ≈ 2.82 GHz	Single-band behavior and relatively complex structure
This study	Rectangular Slotted MPA	Multiple rectangular slots on patch	Wide bandwidth (≈ 4.73 GHz) and gain up to ≈ 6.75 dB

Methodology

This section describes the systematic procedure adopted for designing, modeling, and simulating the proposed multiband microstrip patch antenna. The methodology includes defining design requirements, selecting suitable materials, developing the antenna geometry, implementing performance enhancement techniques, and evaluating the antenna using full-wave electromagnetic simulation.

The design process begins by defining the fundamental requirements of the antenna based on its intended application in modern mobile and wireless communication systems. The antenna is required to operate over multiple frequency bands covering Wi-Fi, WLAN, WiMAX, and IMT applications while maintaining compact size, acceptable gain, and good impedance matching. Key design parameters such as operating frequency range, bandwidth, substrate properties, and feeding technique are selected accordingly. Table(2) summarizes the main specifications considered during the design process, including antenna type, application, substrate material, and feeding method.

Table 2: The specifications for the design purpose of the structure

NO	Parameters	Specifications
1	Type of antenna	Rectangular MPA
2	Application	For mobile communication
3	Substrate	FR-4
4	Feeding method	Microstrip Line feeding

Antenna Design:

The design of a rectangular microstrip patch antenna is based on several fundamental theoretical and geometric parameters that directly affect its performance. In general, the patch length L is selected within the range $0.333\lambda_0 < L < \lambda_0$, where λ_0 represents the free-space wavelength. The patch thickness (t) is typically much smaller than λ_0, ensuring a thin and compact antenna structure. The dielectric constant of the substrate usually ranges between 2.2 and 12, while the substrate thickness (h) is commonly chosen within the range $0.003\lambda_0 \leq h \leq 0.05\lambda_0$ [17-22]

Based on these theoretical considerations, the essential design parameters include the operating frequency (f_0), the dielectric constant of the substrate (ε_r), the substrate thickness (h), the conductor thickness (ht), the patch width (W), the patch length (L), as well as the width and length of the ground plane and substrate (Wg and Lg),[17-22] as illustrated in Figure (1).

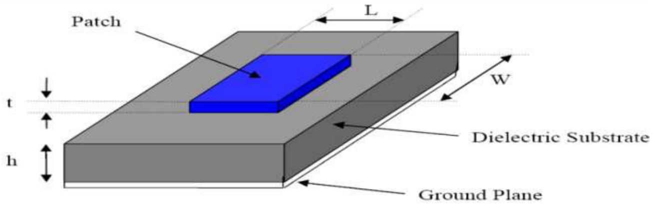

Figure 1: Rectangular microstrip patch antenna

The width of the microstrip line is given by [5-22]:

$$W = \frac{1}{2fr\sqrt{\mu_0 \varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{\vartheta_0}{2fr}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

extension of the length of the patch is given by[5-22]:

$$\Delta L_{eff} = 0.412h\,\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \quad (2)$$

calculate the effective length, we add the length L to the extension of the length ΔL [5-22]:

$$L_{eff} = (L + 2\Delta L_{eff}) \quad (3)$$

The effective dielectric constant ε_reff from the formula [5-22]:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12h}{w}}} \quad (4)$$

The resonant frequency is given by [5-22]:

$$f_r = \frac{\vartheta_0}{2\sqrt{\varepsilon_{reff}}\,(L + 2\Delta L_{eff})} \quad (5)$$

The proposed multiband microstrip patch antenna is designed to operate efficiently over a wide frequency range from 2.4 GHz to 8 GHz. An FR-4 substrate with a dielectric constant of εr=4.4 and a thickness of 1.57 mm is employed. The antenna consists of a rectangular radiating patch printed on the top surface of the substrate and a conducting ground plane placed on the bottom surface.

To enhance the impedance bandwidth and enable multiband operation, rectangular slots are introduced into the antenna structure, and the ground plane is partially reduced. These modifications effectively alter the surface current distribution and generate multiple resonant modes, leading to improved antenna performance.

The antenna is modeled and simulated using CST Microwave Studio 2019. Its performance is evaluated in terms of return loss (S_{11}), impedance bandwidth, voltage standing wave ratio (VSWR), gain, directivity, and surface current distribution.

As illustrated in Figure (2), the proposed patch antenna has a rectangular geometry incorporating two rectangular slots and a notch on the radiating patch to enhance its performance. The antenna is excited using a microstrip line feed, which is carefully designed to provide an input impedance close to 50 ohms, ensuring efficient power transfer and reduced reflection losses.

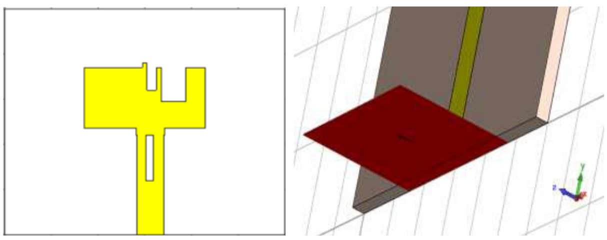

Figure 2: Simulated view of the antenna from CST (a) full view 3D; (b) view with feed

The detailed dimensions of the substrate, radiating patch, ground plane, and feed line are summarized in Table (3). The antenna structure is modeled and simulated using CST Microwave Studio, and the simulated three-dimensional views of the antenna, including the complete structure and the feeding configuration, are presented in Figure (2a).

Table 3: Antenna Parameters

No.	Parameter	Value(mm)	Description
1	Ws * Ls	60*70	Substrate Dimensions
2	Wp *Lp	26*14.4	Patch Dimensions
3	Wg * Lg	60 * 23	Ground Dimensions
4	Wf * Lf	5.6 * 22	Feed line Dimensions
5	hs	1.57	Thickness of the substrate
6	hg	0.035	Thickness of the Ground
7	**hp**	**0.035**	Thickness of the Patch

Result and Dissection

The antenna characteristics are evaluated in terms of return loss (S_{11}), voltage standing wave ratio (VSWR), directivity, gain, three-dimensional radiation patterns, and surface current distribution at the main resonant frequencies. The obtained results are discussed in relation to the antenna structure, with particular emphasis on the effect of the introduced rectangular slots and the partially reduced ground plane.

Table (4) summarizes the key antenna performance parameters for both the slotted and non-slotted configurations. It is clearly observed that the introduction of slots significantly improves the antenna behavior, enabling multiband operation, wider bandwidth, and enhanced radiation characteristics compared to the conventional design.

Table 4: Antenna Parameters with and without slots

Frequency GHz	**With Slot**					**Without slot**
	2.8	3.8	5.3	6.7	7.6	3.65
S_{11}	-9.7	-36.3	-25.1	-26.1	-10.1	-13.9
VSWR	1.86	1.029	1.118	1.107	1.897	1.499
Dir(db)	5.721	6.466	6.232	8.205	9.430	3.482
Gain(db)	2.833	4.167	5.351	6.752	8.705	3.351

Return Loss(S_{11}) the simulated reflection coefficient (S_{11}) results indicate good impedance matching at the resonant frequencies. The antenna achieves minimum S_{11} values of −36.31 dB at 3.8 GHz and −26.01 dB at 6.7 GHz, confirming efficient power transfer and successful excitation of multiple resonant modes. Compared to the antenna without slots, the slotted design exhibits improved impedance matching across a wider frequency range, demonstrating the effectiveness of slot loading in multiband antenna design. The simulated return loss characteristics are illustrated in Figure (3).

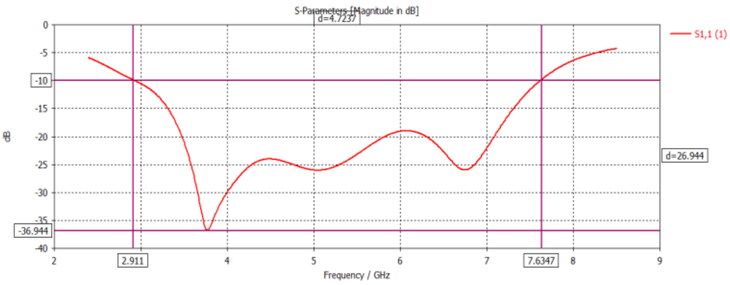

Figure 3: Return Loss Performance of the Proposed Slotted MPA

Voltage Standing Wave Ratio (VSWR) the voltage standing wave ratio is an important parameter for assessing antenna impedance matching, and acceptable performance is generally achieved when VSWR lies between 1 and 2. As shown in Figure (4), the simulated VSWR values remain below 2 over the entire operating bandwidth of the antenna. Specifically, the VSWR is approximately 1.86 at 2.9 GHz, corresponding to Wi-Fi and Bluetooth applications, and approaches 1.02 at 3.8 GHz, which is suitable for WiMAX operation. These results confirm good impedance matching with a standard 50-ohm feed line across all operating bands.

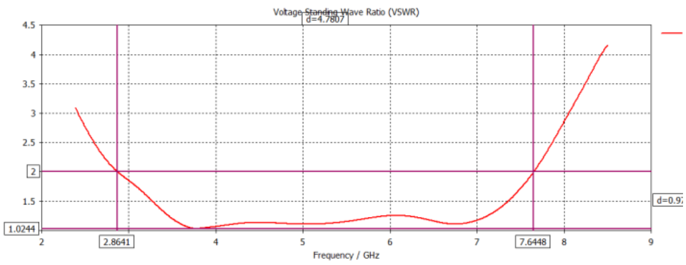

Figure 4: VSWR Performance of the Proposed Slotted MPA

The directivity performance of the proposed antenna is analyzed at selected resonant frequencies. The three-dimensional directivity patterns at 2.8 GHz, 3.8 GHz, and 5.3 GHz are shown in Fig 5 (a–c), respectively. The antenna exhibits directivity values of 5.72 dBi at 2.8 GHz, 6.46 dBi at 3.8 GHz, and 6.23 dBi at 5.3 GHz. An increasing trend in directivity is observed at higher frequencies, reaching a maximum value of 9.43 dBi at 7.6 GHz, which indicates improved radiation focus due to the slot configuration and ground plane modification.

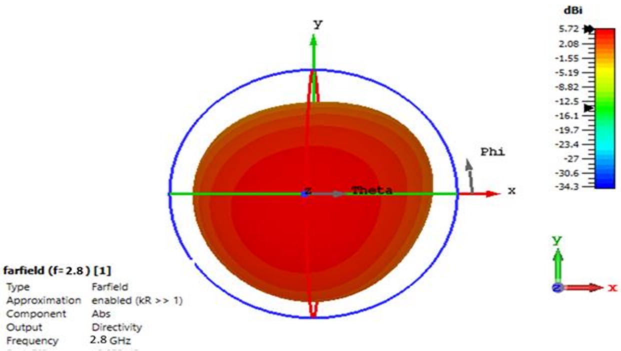

Figure 5: (a) 3D plot of Directivity of MPA at 2.8 GHz

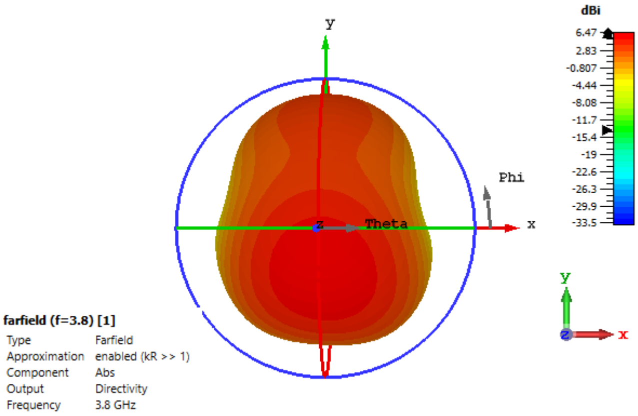

Figure 5: (b) 3D plot of Directivity of MPA at 3.8 GHz

The Gain in Figure 6 (a–c) presents the three-dimensional gain patterns of the slotted microstrip patch antenna at the resonant frequencies of 2.8 GHz, 3.8 GHz, and 5.3 GHz. The simulated gain values are 2.83 dB, 4.16 dB, and 5.35 dB at these frequencies, respectively. Higher gain values of 6.75 dB at 6.7 GHz and 8.71 dB at 7.6 GHz are also achieved, demonstrating a significant improvement compared to the antenna without slots. This enhancement confirms the positive impact of aperture loading on radiation efficiency.

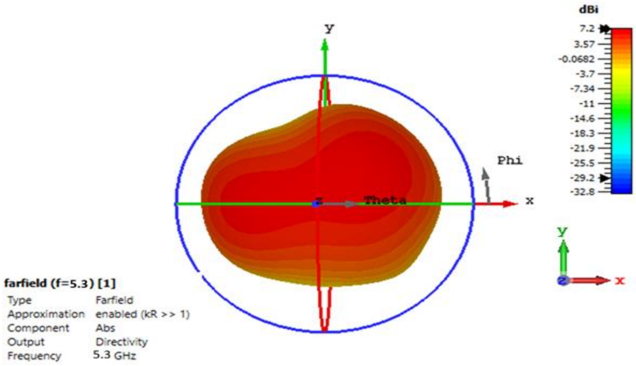

Figure 5: (c) 3D plot of Directivity of MPA at 5.3 GHz

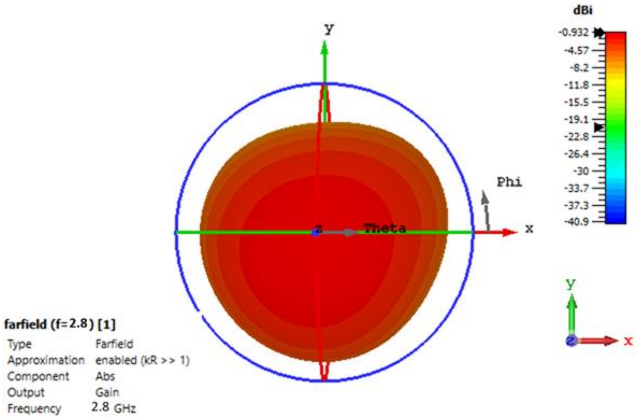

Figure 6: (a) 3D plot of Gain of slotted MPA at 2.8 GHz

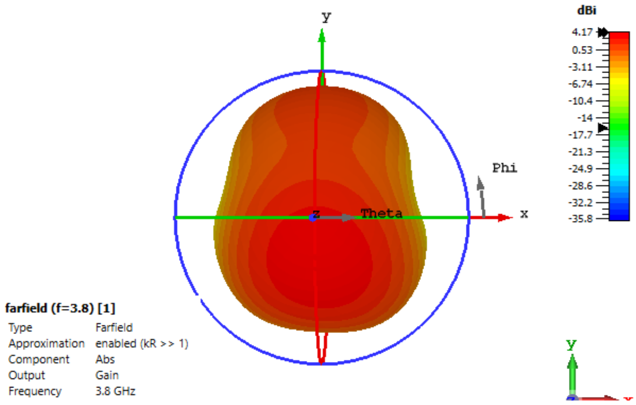

Figure 6: (b) 3D plot of Gain of slotted MPA at 3.8 GHz

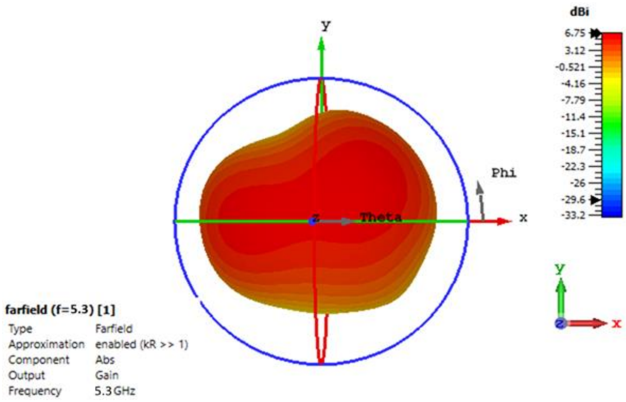

Figure 6: (c) 3D plot of Gain of slotted MPA at 5.3 GHz

The surface current distribution provides insight into the radiation mechanism of the antenna. Fig 7 (a–c) shows the surface current plots at the resonant frequencies of 2.8 GHz, 3.8 GHz, and 5.3 GHz. Strong current concentrations are observed around the rectangular slots and along the edges of the patch and ground plane. These current paths confirm that the introduced slots play a crucial role in generating multiple resonant modes and improving the overall antenna performance.

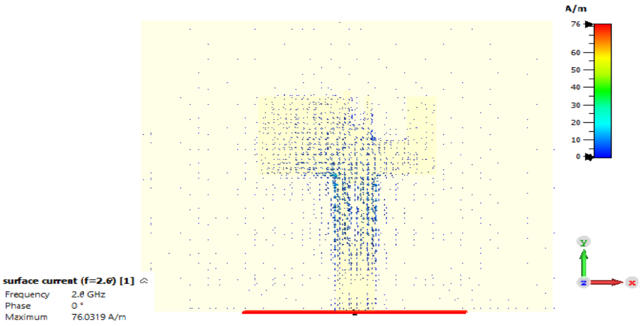

Figure 7: (a) Surface current plot of MPA at 2.8 GHz

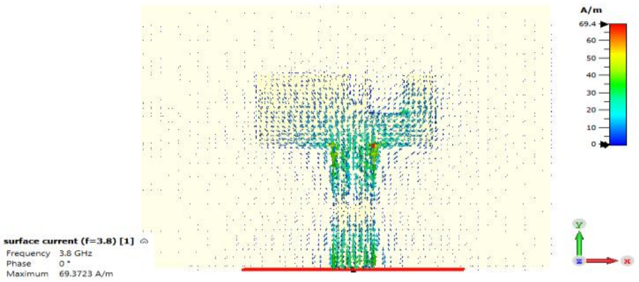

Figure 7: (b) Surface current plot of MPA at 3.8 GHz

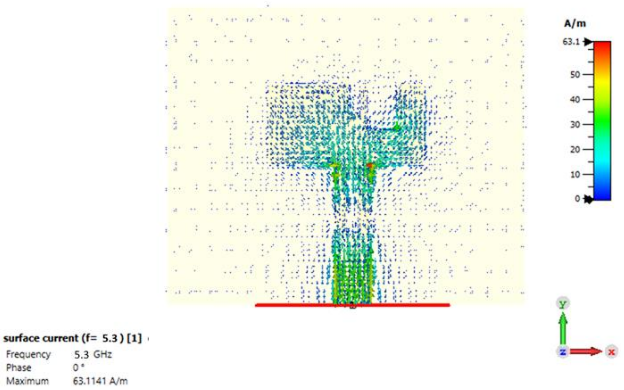

Figure 7: (c) Surface current plot of MPA at 5.3 GHz

Overall, the results clearly demonstrate that the proposed slotted microstrip patch antenna outperforms the conventional design without slots. The improvements in return loss, bandwidth, gain, and directivity validate the effectiveness of slot loading and partial ground plane reduction. These characteristics make the proposed antenna a strong candidate for practical applications in portable and smartphone wireless communication systems.

Conclusion

This paper investigates the enhancement of microstrip patch antenna performance using slot loading and partial ground plane modification. The comparison shows that adding slots significantly improves the antenna's performance. The conventional antenna has narrow bandwidth and a single resonance at 3.65 GHz, while the slotted design achieves wider bandwidth, better impedance matching (S_{11} as low as −36.31 dB at 3.8 GHz), and VSWR close to 1. Radiation performance is also enhanced, with gain up to 8.71 dB and directivity up to 9.43 dB. Overall, the proposed antenna offers wide bandwidth, high gain, compact size, and stable multiband operation, making it suitable for modern mobile and wireless communication systems. Slot loading with partial ground modification proves to be an effective method for performance enhancement.

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