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Compact DGS-Integrated Microstrip Antenna for Dual-Band Wireless Communication Systems

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Abstract

This paper introduces an innovative circular microstrip patch antenna design featuring a defected ground structure (DGS) for enhanced wireless communication performance. With compact dimensions of 35 mm × 30 mm × 1.59 mm, the proposed antenna demonstrates a wide impedance bandwidth of 2.70 GHz (2.305.01 GHz) and consistent gain characteristics averaging 3 dBi. Simulation results obtained through CST Microwave Studio confirm the antenna's effectiveness for simultaneous operation in WLAN, WiMAX, and lower UWB frequency bands.

Keywords: Dual-band antenna, defected ground structure, wireless networks, impedance bandwidth, radiation efficiency

INTRODUCTION

The IEEE has allocated multiple frequency bands for WLAN operations, including 802.11, 802.11b, and 802.11g at 2.4 GHz, and 802.11a at 5 GHz. Additionally, the high-speed 802.11n standard supports both 2.4 GHz and 5 GHz bands [1, 2]. With the increasing demand for compact communication devices, printed patch antennas have emerged as a preferred solution due to their low profile, lightweight, and ease of integration. However, these antennas often suffer from limitations such as narrow bandwidth, low gain, and limited power handling capacity [3, 4].

To address these challenges, researchers have explored various techniques, including the use of Defected Ground Structures (DGS). Initially introduced as a photonic bandgap (PBG) unit by Kim et al. [7, 8], DGS was later refined to enhance antenna performance by modifying the ground plane [9]. The shape and dimensions of the defect play a crucial role in controlling electromagnetic wave propagation and improving bandwidth and gain [10].

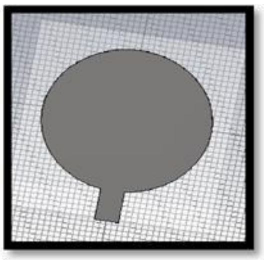
In this work, a circular patch antenna with a finite ground plane is enhanced using DGS to achieve superior performance in terms of bandwidth and gain. The design process and comparative analysis of the antenna with and without DGS are detailed in the following sections.

ANTENNA DESIGN AND ANALYSIS

The proposed antenna started with conventional circular patch antenna (overall size 35mm*30mm) with patch radius 13.0 mm which is designed on Glass Epoxy FR-4 substrate having relative permittivity εr = 4.4, substrate height h =

1.59 mm and loss tangent = 0.025. These dimensions were selected to design an antenna to resonate in the frequency band allocated for the lower band for WI-Max applications. We applied a 50ohm microstrip line having length 7.0 mm and width 4.6 mm for feeding purpose. In the first stage, a microstrip fed circular antenna with finite ground plane as shown in Fig.1a & 1b is simulated using CST Studio suite 2013 [11].

The simulation results shown in Fig. 2 indicate that antenna resonates effectively at frequency 6.13 GHz. The bandwidth presented at this frequency is very narrow (~3.8%), while gain of antenna is very low. The simulation results provide higher resonance frequency value than desired. Therefore, this antenna in its present form needs further modification to find possible application in modern wireless communication systems.



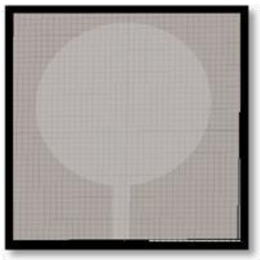


Fig.1a

Front view of proposed antenna Fig. 1b Rear view of proposed antenna

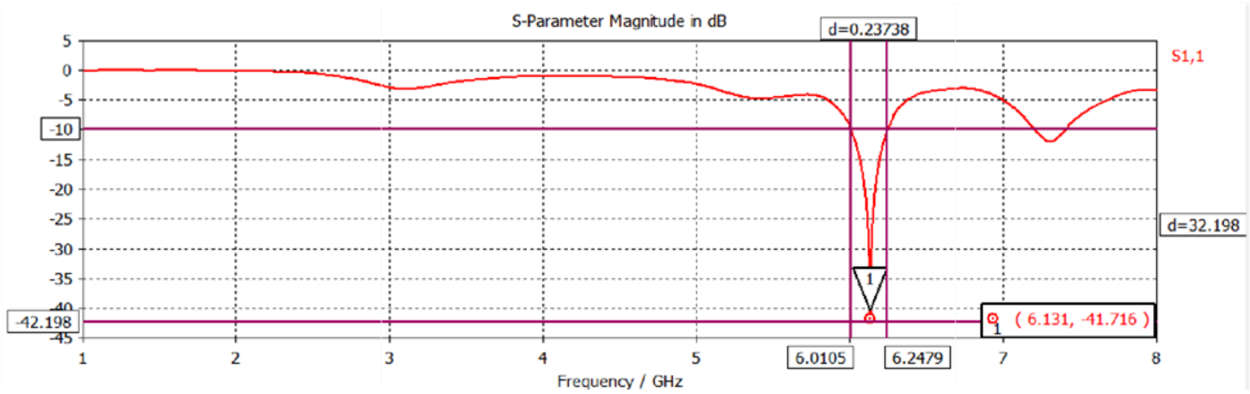


Fig. 2 Simulated variation of reflection coefficient with frequency for proposed antenna with finite ground plane

This antenna is further modified by using DGS technique, it is realized that defect in ground plane further modifies the performance of antenna to a larger extent [12-13]. A triangular slot of base length 20mm & height 18mm is applied in it as shown in fig. 3 (a-b). With introduction of this triangular slot, the current in ground plane gets modified and that change in turn improves the performance of antenna. For further improvement in antenna performance, an additional triangular notch is introduced in ground plane having base length 10mm and height 4mm. With these modifications; an additional resonance frequency close to 4.36 GHz is realized with further improvement in gain as well as in bandwidth values of antenna.

The return loss curves shows that modified antenna is resonating at two frequencies 2.70GHz and 4.36 GHz as shown in Fig. 4 and provides impedance bandwidth close to 2.70GHz or ~70% with respect to frequency 3.85 GHz. Fig. 5 depicts the simulated variation of gain with frequency for proposed structure. The maximum gain achieved in this case is close 3.22dBi with respect to frequency 3.47GHz which is improved considerably from previous case.

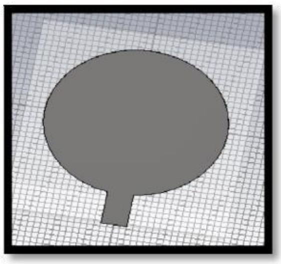


Fig. 3a Front view of modified proposed antenna

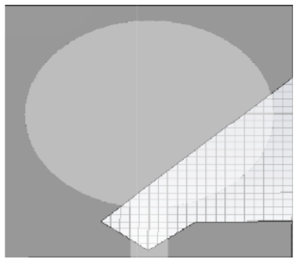


Fig. 3b Rear view of modified proposed antenna

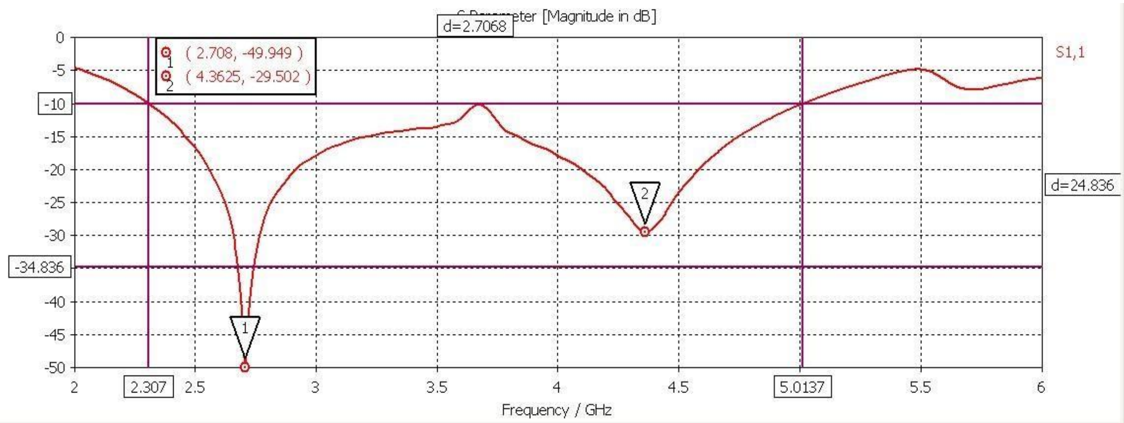


Fig. 4 Simulated variation of reflection coefficient with frequency

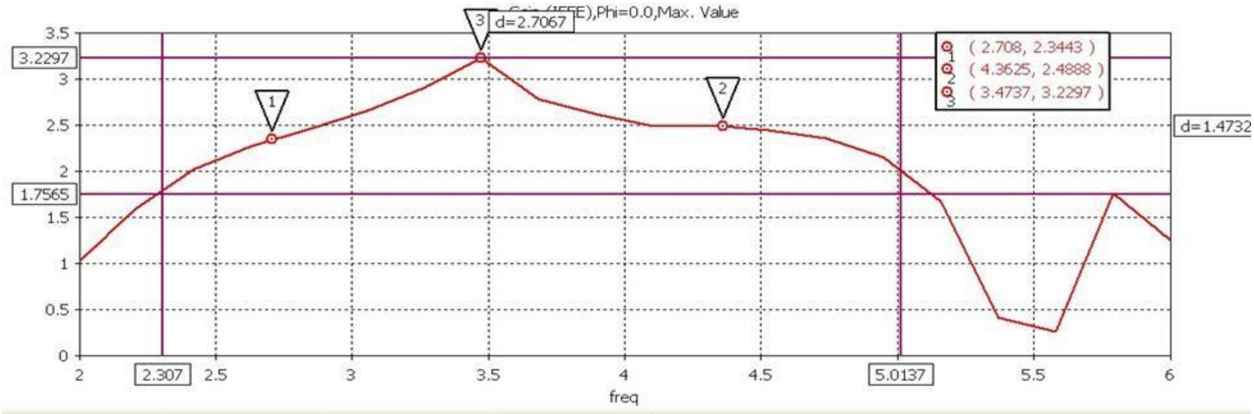


Fig. 5 Simulated variation of gain with frequency

RESULTS

The strip line fed circular patch antenna with defected ground plane provides much improved impedance bandwidth ~2.70GHz or 70% with respect to central frequency 3.85 GHz as shown in Fig.4.The proposed antenna resonates at two frequencies namely 2.70 GHz and 4.36 GHz. The first frequency may be used for lower band in Wi-Max communication systems while the second frequency is suitable for lower band of UWB communication systems. The variation of gain of antenna as a function of frequency is shown in Fig. 5 indicates that gain of antenna in the operating frequency range is almost flat. The maximum gain of antenna is close to 3.22 dBi at frequency 3.47GHz. E and H plane radiation patterns of antenna at two resonant frequencies are shown in Figs. 6a – 6d. Fig. 6a indicates that antenna is radiating more power in back direction. However, patterns are almost omni directional, three figures have dumbell shape which suggests that radiation pattern resembles with that of a dipole antenna.

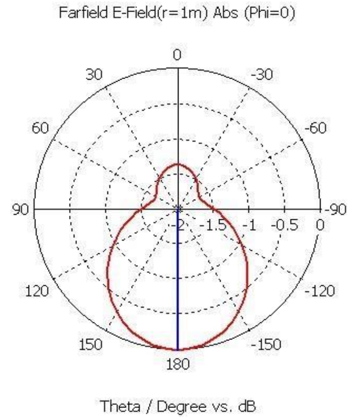


Fig. 6a E plane (Phi=0) radiation pattern at resonant frequency

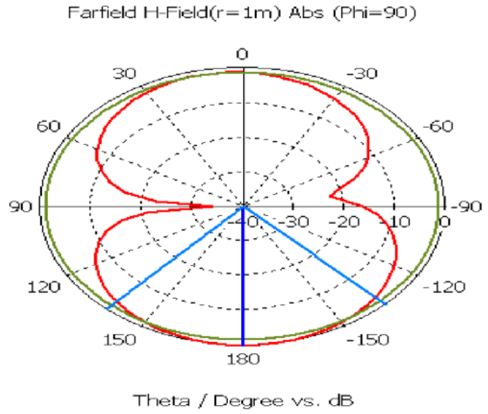


Fig. 6b H plane(Phi=90) radiation pattern at resonant frequency

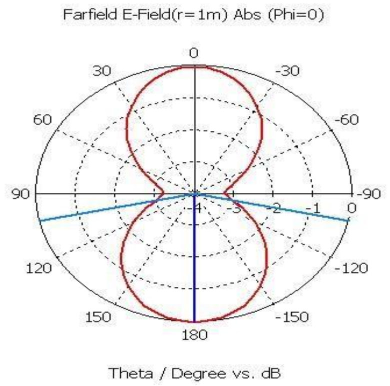


Fig. 6c E plane (Phi=0) radiation pattern at resonant frequency

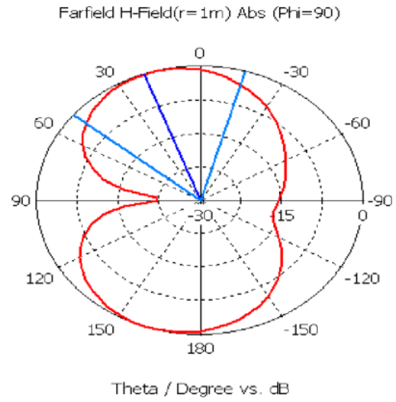


Fig. 6d H plane (Phi=90) radiation pattern at resonant frequency

CONCLUSION

The proposed compact circular microstrip patch antenna with a defected ground structure (DGS) demonstrates significant performance enhancements compared to conventional patch antenna designs. Through careful optimization of the ground plane geometry, including the introduction of triangular slots and notches, the antenna achieves remarkable improvements in both bandwidth and gain characteristics. The modified design exhibits an exceptionally wide impedance bandwidth of 2.70 GHz (2.30-5.01 GHz), representing approximately 70% fractional bandwidth relative to the center frequency of 3.85 GHz. This substantial bandwidth improvement directly addresses one of the most critical limitations of traditional microstrip patch antennas, making the proposed design particularly suitable for modern broadband wireless communication systems.

The antenna's dual-resonant behavior at 2.70 GHz and 4.36 GHz provides excellent coverage for multiple important wireless communication standards. The lower resonance frequency of 2.70 GHz makes the antenna ideal for WiMAX applications (2.3-2.7 GHz), while the higher resonance at 4.36 GHz effectively covers the lower band of ultra-wideband (UWB) systems (3.1-4.8 GHz) and portions of the 5 GHz WLAN band. This dual-band operation capability significantly enhances the antenna's versatility and practical utility in real-world communication scenarios where multiple frequency bands need to be supported simultaneously. The gain performance of the proposed antenna represents another notable improvement over conventional designs. The maximum gain of 3.22 dBi achieved at 3.47 GHz, combined with relatively flat gain characteristics across the entire operating bandwidth, ensures consistent radiation performance. This stable gain profile is particularly advantageous for maintaining reliable communication links in wireless systems where signal strength variations can degrade performance. The radiation patterns maintain desirable omnidirectional characteristics while showing improved front-to-back ratio compared to the initial design without DGS, further enhancing the antenna's practical effectiveness.

The success of this design approach validates the effectiveness of defected ground structures in overcoming the inherent limitations of microstrip patch antennas. The strategic modification of the ground plane geometry alters the current distribution and electromagnetic field patterns in ways that simultaneously improve multiple performance parameters. This research contributes to the growing body of knowledge on DGS applications in antenna design, providing specific insights into how triangular-shaped defects can be optimized for broadband performance. Future research directions could explore several promising avenues. First, the investigation of alternative defect geometries beyond triangular shapes may reveal additional performance optimization opportunities. Second, the integration of reconfigurable DGS elements could enable dynamic tuning of the antenna's operating characteristics. Third, the application of advanced materials with lower loss tangents could potentially further improve the antenna's efficiency and bandwidth. Finally, the development of array configurations based on this unit cell design could yield solutions for applications requiring higher gain or beam-steering capabilities. From a practical implementation perspective, the antenna's compact dimensions (35 mm × 30 mm × 1.59 mm) and use of standard FR-4 substrate make it highly suitable for integration into modern communication devices where space constraints are critical. The design's compatibility with conventional PCB fabrication processes ensures costeffective manufacturability, an essential consideration for commercial applications. These attributes position the proposed antenna as a strong candidate for next-generation wireless systems, including IoT devices, portable communication equipment, and compact base station applications. In summary, this work presents a comprehensive solution to several longstanding challenges in microstrip patch antenna design. By successfully combining broadband operation, stable gain performance, and compact form factor through innovative DGS implementation, the proposed antenna design meets the demanding requirements of contemporary wireless communication systems. The theoretical analysis, simulation results, and performance comparisons presented in this study provide valuable insights for antenna researchers and engineers working on similar broadband compact antenna solutions. The design methodology and optimization techniques developed through this research can be readily extended to other antenna configurations, potentially leading to further advancements in the field of compact broadband antenna design.

Conflicts of Interest: All authors declare that they have no conflict of interest associated with this research work.
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