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"PERFORMANCE ANALYSIS ON 1*2 L SHAPED MICROSTRIP PATCH ANTENNA FOR 2.4GHz"

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Abstract: The demand increasing for the wireless communication system has been driven for the significant research into antenna designs that offer improved performance at standard communication frequencies. Among these, the 2.4 GHz band remains a critical range for applications such as Wireless Local Area Networks (WLAN) and Wi-Fi. Microstrip patch antennas (MPA) are widely favored in such systems due to their low profile, ease of fabrication, and compatibility with planar and non-planar surfaces. However, conventional single-element patch antennas often face limitations in terms of bandwidth, gain, and impedance matching.

To improve these circumstances, researchers have explored a variety of geometrical modifications and array configurations. One such approach involves the implementation of L-shaped patch geometry, which have to been shown to enhance bandwidth and impedance characteristics through their altered current distribution and resonant modes. Additionally, array configurations, particularly linear arrays like the 1×2 design, are known to significantly improve gain and directivity by effectively combining the radiation from multiple elements.

In this subject of context, the present research focuses on the designing and simulation of a 1×2 L-shaped MPA array tailored for 2.4 GHz operation. The MPA is developed using the software called "CST Studio Suite", a widely used electromagnetic simulation tool, and its performance is assessed based on critical parameters including return voltage standing wave ratio (VSWR), return loss, gain, radiation pattern and bandwidth. The simulation results reveal that the designed antenna configuration not only offers low return loss and efficient impedance matching but also achieves enhanced gain and a directional radiation pattern, there by presenting its capacity for integration into modern wireless communication (MWC) systems operating in the 2.4 GHz band.

Keywords: Microstrip Patch Antenna, 1×2 Antenna Array, Radiation Pattern, Wireless Communication, CST Studio, Gain, Return Loss, VSWR

I. INTRODUCTION

The evolution of communication throught wireless has intensified the need for antenna system that not only provide the high performance but also meet practical constraints such as size, cost, and manufacturability. MPAs have been recognized in this context for their low weight, compact form factor of integration with printed circuit boards(PCB) and other planar technologies. These advantages have made them the preferred choice for wireless communication system applications, including wireless local area networks (WLAN), mobile phones, Bluetooth-enabled devices, and the expanding ecosystem of the Internet of Things (IoT). Operating effectively within the 2.4 GHz Scientific, Industrial and Medical (ISM) band, these antennas support a broad range of devices that require reliable and efficient signal Tx in compact environments. Their structural compatibility and simplicity with modern days fabrication techniques further reinforce their suitability for high-volume, low-cost wireless solutions.

II. LITERATURE SURVEY

In recent work, a novel MPA was designed particularly for circularly polarized satellite communication, incorporating structural innovations to achieve high performance and compactness (Fawzy et al., 2024). The antenna employs a square patch integrated with two L-shaped slots positioned at opposite diagonal corners to facilitate circular polarization. Additionally, four axial slots aligned along the symmetry axes contribute to bandwidth enhancement and overall size reduction. Constructed using Rogers TMM4 substrate, the design benefits from the material's consistent dielectric properties, ensuring stable operation at a target frequency of 8.1 GHz—making it applicable for both satellite and

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synthetic aperture radar (SAR) systems. The measured performance includes an impedance bandwidth of approximately 600 MHz and bandwidth of 170 MHz . A notable feature is the antenna's ability to switch between right-hand and left- hand circular polarisation by modifying the positions of the L-shaped slots. With a gain of 6.4 dBic and low cross-polarisation levels, the radiation patterns exhibits good symmetry. The simplicity of the single-feed design and straightforward slot configuration supports ease of fabrication and cost-effectiveness. Simulation and measurement results align closely, demonstrating that the MPA is not only compact and lightweight but also well-suited for space-constrained satellite applications. Overall, the design provides an efficient and reliable option for circularly polarised systems. [1]

Zambak et al. (2023) introduced a compact L-shaped MPA specifically optimized for applications like Internet of Things (IoT) operating in the 2.4 GHz ISM bandwidth. Designed with size-sensitive devices in mind, the antenna features a minimal footprint of just 28 mm × 21 mm × 1.6 mm, making it highly compatible with modern, compact electronics. The design incorporates a full ground plane coinside with a small rectangular slot, which provide performance results such as impedance matching and bandwidth. Fabricated on a cost-effective FR-4 substrate, the antenna achieves a balance between affordability and operational efficiency. The study reports excellent alignment between measured data, validating the reliaability of the design.The antenna demonstrates a high radiation efficiency of 98%, a critical requirement for low-power IoT devices. With a gain of 2.09 dBi and a return loss consistently below −10 dB at the operating frequency, the design ensures reliable short-range communication. Its omnidirectional radiation pattern supports even signal distribution, which is especially beneficial for indoor and dense deployment scenarios. Applications such as smart home systems, wireless sensor networks, and real-time asset tracking stand to benefit from the antenna's design attributes. The authors also conducted an in-depth parametric analysis to fine-tune antenna characteristics. Due to its straightforward geometry, the antenna is well-suited for integration into embedded systems and is compatible with mass production techniques. Overall, the design offers a practical and efficient solution for compact IoT devices requiring consistent and robust wireless connectivity.[2]

Pallavi et al. (2024) present a novel approach to enhancing aircraft navigation systems through the development of a metamaterial structure that combines U-shaped and L-shaped resonators. The design aims to improve key antenna performance parameters— specifically gain and bandwidth—within the context of Airborne Collision Avoidance Systems (ACAS). The proposed metamaterial employs a compact unit-cell configuration capable of exhibiting negative permittivity and permeability, thus achieving a negative refractive index in the X-band frequency range, which is commonly used in aviation communications. The research incorporates both computational simulations and physical prototyping to confirm the potential of structure. Experimental results confirm that integrating the metamaterial with conventional antennas yields notable improvements in gain and operational bandwidth. This is particularly very beneficial for the applications requiring precise and reliable aircraft positioning and collision mitigation. The fabrication process is mainly compatible with the standard printed circuit board (PCB) technologies, underlining the practicality of the design for real-world aviation systems. Moreover, the study systematically explores how variations in the geometric dimensions of the resonators influence the electromagnetic behavior of the metamaterial. The findings support the potential of this dual-resonator approach in tailoring electromagnetic responses to meet the demanding requirements of aerospace communication systems. By advancing the capabilities of ACAS antennas, this work establishes a strong foundation for the further explorations of metamaterial-assisted antenna design in aeronautical applications.[3]

Varshini et al. (2017) conducted a performance evaluation of U-shaped MPA designed for operation within the terahertz (THz) frequency range. The research focuses on optimizing antenna geometry to improve the performances such as return loss, radiation efficiency, and bandwidth. Leveraging electromagnetic simulation tools, the authors explore how variations in structural parameters influence the antenna's impedance characteristics and radiation behavior. The U-shaped configuration is selected due to its inherent capacity to support multiple resonant modes(MRM), which is instrumental in achieving wider bandwidths—a crucial requirement in THz communications. The research highlights the suitability of compact U-shaped designs for integration into THz systems, where miniaturization and precision are essential. The paper addresses the fabrication challenges associated with THz frequency components, emphasizing the need for meticulous design and manufacturing techniques. Additionally, the study outlines prospective applications of these antennas in domains such as terahertz imaging, high-resolution spectroscopy, and next-generation wireless technologies. The findings will be issue most valuable perceptions into the design methodology of efficient THz antennas, serving as a point for future work in both simulation-based and experimental research. The authors also helps for further investigation into alternative substrate materials and advanced fabrication processes to enhance antenna performance at these high frequencies. Overall, the study makes a significant contribution to the evolving field of terahertz antenna design.[4]

Mak and Luk (2000) conducted a detailed experimental analysis of a MPA employing an L-shaped probe feed to improve wider bandwidth and improve radiation characteristics. The L-shaped probe introduces a form of capacitive coupling that significantly broadens the impedance bandwidth compared to traditional coaxial probe feeds.

The antenna is implemented on a relatively thick substrate— approximately 10% of the operating wavelength—which is instrumental in supporting wideband functionality. The study reports an impedance bandwidth of around 20%, marking a substantial advancement over conventional MPA designs. Importantly, the radiation patterns remain stable across the entire operating range, maintaining high polarization purity and exhibiting minimal cross-polarization. The research also improves how variations in the probe dimensions and substrate thickness affect the antenna's performance. It is found that meticulous tuning of these parameters can lead to further improvements in gain and bandwidth. One of the notable advantages of the L-shaped probe is its non-contacting feed mechanism, which simplifies fabrication and helps minimize potential signal losses. The paper combines both theoretical modeling and empirical data, offering a comprehensive perspective on the design's effectiveness. Furthermore, the authors propose extending the concept to include circularly and dual-polarized antenna designs, highlighting its versatility. This study provide as a foundational reference in the developments of broadband microstrip antennas and demonstrates the practical viability of L- shaped probe feeding techniques.[5]

Ma and Jiang (2020) proposed an innovative ultra-wideband (UWB) microstrip antenna design that integrates L-shaped slots and a stepped-impedance resonator (SIR) to significantly extend bandwidth performance. The antenna is fabricated on a Rogers 4350 substrate with compact dimensions of 36 mm × 23 mm. Initially, the structure demonstrated limited bandwidth; however, the introduction of the SIR topology broadened the operational frequency range from 2.4 GHz to 11.29 GHz. To further enhance performance, symmetric L- shaped slots were incorporated along the patch edges, expanding the bandwidth up to 13.16 GHz. The antenna maintained a reflection coefficient below −10 dB across the entire operating band, indicating effective impedance matching. Through detailed parametric analysis, the study highlighted that the length and width of the L-shaped slots perform a important role in shaping impedance bandwidth and refining in-band performance. The optimized design achieved enhanced increased radiation efficiency, key parameters for reliable UWB communication. This work underscores the potential of combining stepped-impedance resonators with strategically placed L- shaped slots to create compact, high-performance UWB antennas. The approach offers a practical solution for wideband wireless systems, including applications in high-speed data transmission, radar imaging, and short-range communication technologies.[6]

Guan and Fujimoto (2020) proposed a wideband microstrip patch antenna tailored for medical BAN(body area network) applications, utilizing an L-shaped feed mechanism to enhance performance. The antenna employs a proximity-fed rectangular patch structure where the L-shaped feed line excites dual resonant modes, effectively broadening the impedance bandwidth. Careful tuning of the feed line's physical length facilitates a lower resonant frequency centered at 2.4 GHz, while modifications to the patch geometry enable control over the higher frequency response, thus expanding the overall operational bandwidth. The compact and low-profile design makes it suitable for wearable medical devices, where space and flexibility are critical.The results of simulation show improvements in return loss and radiation characteristics. Moreover, the antenna exhibits stable and improved performance even when subjecte to different body postures, demonstrating its reliability for continuous health monitoring in dynamic real-world conditions. The study confirms the suitability of L- shaped fed microstrip antennas for wearable healthcare systems by achieving a balance between size, bandwidth, and radiation stability.[7]

Verma, Kumar, and Agrawal (2023) explored the design of rectangular MPA is designed at 2.4 GHz. Using HFSS simulation software, the researchers optimized the antenna's physical dimensions to achieve enhanced performance metrics. The final design demonstrated a return loss of −25 dB, signifying strong impedance matching. Additionally, the antenna achieved a notable gain of 7.5 dBi and an efficiency of 85%, both are critical for robust wireless connectivity. The radiation pattern analysis revealed omnidirectional characteristics, making the antenna well-suited for applications such as Wi-Fi and Bluetooth, where broad area coverage is essential. Its compact form factor and high-performance metrics make it aadvantageous for integration into portable and space-constrained devices. The design also find how different substrate materials influence the antenna's electrical behavior, noting that material selection can significantly affect overall efficiency and bandwidth. Overall, the research presents a practical and effective antenna solution that balances physical size with desirable electrical properties. The findings contribute to ongoing efforts to develop compact, efficient antennas for next-generation wireless systems.[8]

Benlakehal et al. (2022) presented a cutting-edge 1×2 MPA array that integrates photonic crystals and graphene loading to optimize performance for terahertz (THz) applications. The antennas are operates at a frequency of 0.630 THz, achieving an exceptionally low return loss of −73.86 dB and a wide operational bandwidth of 287 GHz. With a gain of 11.11 dB, the design showcases significant advancements in high-frequency antenna engineering.One of the improved features of this work is the tunability of antenna characteristics through the modulation of graphene's chemical potential.

Additionally, the use of non-periodic photonic crystal structures contributes to enhanced gain and broader bandwidth. Although this study is centered on THz frequency operation, the methodologies and material innovations presented—such as graphene loading and photonic crystal integration—offer valuable insights that can be adapted for the development of high-efficiency antennas in lower frequency bands, including 2.4 GHz. The research highlights the potential of merging novel materials with advanced structural configurations to realize high-performance antenna systems, especially in contexts demanding precise frequency control and wideband capabilities.[9]

Arora et al. (2021) investigated the development of a MPA designed to operates at the 2.4 GHz frequency, targeting applications in Wi-Fi and Bluetooth communication. The antenna utilizes a rectangular MPA mounted on an FR4 substrate(lossy), chosen for its relative dielectric constant of 4.4 and affordability. Through simulation, the antenna demonstrated a return loss of −28 dB and a 100 MHz bandwidth, reflecting strong maching impedance and satisfactory spectral performance.The antenna achieved a gain of 6.2 dBi and exhibited a stable, directional radiation pattern, making it will suit for integration into portable and low-power wireless devices. Furthermore, the study evaluated how changes in substrate thickness influenced the antenna's operational parameters, offering valuable insights into design flexibility. Given its compact footprint and reliable performance, the proposed model presents a practical and low-cost solution for short-range applications in consumer electronics.[10]

III. CONCLUSION AND FUTURE SCOPE

The review of contemporary research underscores the effectiveness of L-shaped microstrip patch antennas in addressing the design demands of 2.4 GHz wireless communication systems. Their distinctive geometry facilitates extended current paths and supports the excitation of multiple resonant modes, leading to enhanced bandwidth and improved impedance matching. Empirical and simulation-based studies consistently report elevated gain and directivity values, confirming their matches for application’s that required stable and efficient signal propagation, such as WLAN, Bluetooth, and IoT networks. Furthermore, the L-shaped configuration offers an advantageous trade-off between compact form factors, reliable electromagnetic performance, and manageable fabrication complexity. This makes it an attracctive option for the modern wireless applications where space efficiency and performance are both critical. These collective insights validate the L-shaped patch as a strong candidate for more advanced antenna systems, particularly when implemented in array configurations to further amplify performance metrics.

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