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Cost-effective circularly polarized MIMO antenna for Wi-Fi applications

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ABSTRACT

Antenna is a backbone of communication system, and with the advent of technology, numerous innovations have been made to advance antenna development. An antenna, functioning as a smart device, transmits and receives signals while also working as a transducer. Wireless communication requires a useful device for transmitting and receiving electromagnetic waves. Wireless fidelity (Wi-Fi) is a specific type of wireless communication technology used to transmit data over the internet network. The bandwidth and signal coverage of Wi-Fi have significant limitations. Therefore, an antenna is crucial for improving signal reception to address this issue. This article presents the designing and developing of a cost-effective circularly polarized (CP) 2×2 multiple input multiple output (MIMO) antenna customized for Wi-Fi applications. The application of a notched circular patch antenna serves to achieve circular polarization. The radius of the circular patch is 0.26 λ, and the proposed MIMO antenna effectively showcases CP, characterized by an axial ratio (AR) of 1 dB at 5 GHz and an impressive bandwidth spanning 0.2 GHz (4.9-5.1 GHz). Additionally, the antenna is designed to achieve a high-isolation 2×2 MIMO setup, ensuring antenna isolation surpassing 20 dB. By utilizing the flame retardant (FR4) substrate, presented MIMO antenna strikes a balance between cost-effectiveness and operational efficiency for its intended application, and directional radiation patterns are well-aligned within the desired frequency range.

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1. INTRODUCTION

Progress in communication systems includes the promotion of cost-effective, lightweight, low weight, and low profile antennas, which have seen significant improvement over the recent few years [1]. It can maintain high performance across a wide range of frequency spectrums. Because of technological improvements, wireless networks are now implemented everywhere, wireless fidelity (Wi-Fi) is being set up in many locations, including homes, schools, and market centers. All this is coming to an end because of increasing demand for Wi-Fi [2]. There, a high-gain antenna is necessary, and if the antenna has a high gain, it decreases power consumption in devices [3]. In day-to-day laptop usage, patch antennas are utilized. In case the antenna possesses high gain, the laptop can minimize power loss while connecting to an access point that might be far away. Antennas used in these applications should have a mild weight, low profile, offer a broad bandwidth, and be available in small quantities [4].

The design of antennas has been a fundamental field that significantly influences technological progress in wireless communication. Careful antenna design can significantly affect the performance of the wireless communication connection. Many antenna configurations suitable for mobile networks or wireless communication were suggested by many antenna designers [5]. In recent years, researchers have been concentrated on creating a wireless communication system using a multiband antenna due to its compact size, cost-effectiveness, and high data transmission rate. Combining multiband and miniaturization features within a single antenna design are essential for enabling the operation of multiple wireless applications [6]. Multiple input multiple output (MIMO) antenna systems are considered to provide better performance with respect to gain, multiplexing, diversity, reduction of multipath fading, and the augmentation of channel capacity. MIMO technology has a significant role in next-generation mobile communication systems and wireless communication systems, ensuring the delivery of high data rates and capacity [7].

Due to their lightweight nature, potential flexibility, and straightforward fabrication, microstrip antennas offering promising prospects for various applications [8]. However, micro strip antennas (MSAs) have a few limitations. They encounter challenges related to narrow bandwidth, limited realized gain (approximately 30 dB), the generation of surface waves, and operational limitations at higher frequencies due to size constraints. Addressing these kinds of challenges requires exploring various approaches, each involving a different degree of antenna system complexity, to optimize cross-polarization suppression. For better axial ratio (AR) and small arrays, thick linear polarized antennas with individual feed networks work well [9]. They offer 2 dB AR over 30% bandwidth using coupled-slot patches and matched power dividers. For more extensive arrays,the complexity increases, and the performance of single-feed circularly polarized patches on thin substrates is restricted to 0.4-0.6% bandwidth for a 2 dB AR, making it a less complicated selection. Improved resultswere obtained from pairs or sequential-rotation setups with simple feed networks, offering 2-3%bandwidth and 1 dB AR.

These configurations are straightforward but encounter challenges such as reflections, errors affecting bandwidth, and feed-network radiation [10]. For 30 dB cross-polarization discrimination and wide bandwidth, a 2×2 sequential-rotation array works well, suppressing higher modes. Circularly polarized radiators enable the combining cross-polarization discrimination from elements and feed network. Using a single-feed approach with circularly polarized patches simplifies the design and minimizes off-axis cross-polarization effects [11]. However, it’s important to note that these configurations are more susceptible to coupling compared to dual or linear-polarized alternatives. To avoid bandwidth limits, a separate feed network with isolating power dividers is needed for the 2×2 sequential-rotation array [12].

Compact circularly polarized microstrip patch antennas are common in budget-friendly array setups, offering both linear and circular polarization. The uncomplicated method involves adding a diagonal slot to a square patch antenna’s center and fprms the foundation for creating elliptical polarization. A microstrip square patch antenna serves as a linearly polarizedoption and yields either vertical or horizontal polarization based on the feeding approach. Embedding a slot in the patch’s center, changes surface current flow, shifting emission from linearto circular polarization [13].

In this work, cost-effective circularly polarized MIMO antenna for Wi-Fi applications is presented. Following is the structure of the remaining part of the work: section 2 provides the literature survey. In section 3, a cost-effective circularly polarized MIMO antenna for Wi-Fi applications is discussed. The section 4 demonstrates the result analysis. The section 5 describes the conclusion.

2. LITERATURE SURVEY

A new micro-strip patch antenna design is created for Wi-Fi Uses. This study simulates a new semi-star patch antenna design for Wi-Fi applications. Given that of the insertion of rectangular slots into the ground layer, the antenna is operated at 2.4 GHz. The substrate layer is made of FR-4 epoxy; the patch and ground layers are made of copper. FR-4 epoxy has a loss tangent (tanδ) of 0.025 and a :r=4.3. The sizes of the antenna is 45×48×1.6 mm^3. At the operating frequency, the suggested antenna has a gain of 2.8 dB and a reflection coefficient of -41.5 dB. Wi-Fi and WiMAX applications need modifying the antenna [14].

This paper presents the design of a small triple band antenna for WLAN and WIFI 6E applications in narrow border laptop computers. The antenna is 43×3×0.4 mm^3 and has a 200×260 mm^2 copper plate providing as a simulated grounding system. A couple-fed right arm could cover the 2.4–2.848 GHz range at low frequencies through stimulation of the fundamental at 2.45 GHz in the λ/4 resonant mode. At 2.45 and 5.16 GHz, the antenna’s omnidirectional radiation pattern, small size, wide band support, consistent gain, and high efficiency are all present. The results show that the antenna works well with laptops with narrow borders [15].

Microstrip patch antenna design and execution are designed for 5G applications. With a dielectric loss tangent of 0.0010 and a dielectric constant of 2.2, a rectangular patch has been created. The application feldberechnung für Körper with beliebiger oberfläche (FEKO) is used to simulate and analyze this design. After the simulation, the authors reported that the antenna had a broad bandwidth of 3.56 GHz, a high gain of 10 dB, an antenna radiation efficiency of 99.5%, a good return loss of -33.4 dB, and a VSWR <2. This suggested design offers benefits during the current global lockdown situation [16].

A the global system for mobile communication/worldwide interoperability for microwave access/wireless local area network (GSM/WiMAX/WLAN) standards bandwidth requirements are met by the multi-band printed monopole antenna that is explained. The innovation of the presented monopole antenna is the simple design that doesn't require any expensive substrate, reactive components, or any additional hardware. This design operates across multiple frequency bands used in laptop applications, and the antenna structure that is being provided has dimensions of 0.105 λ×0.05 λ, which should be recognized. Considering a lower resonant frequency of 1.8 GHz, the system is only 9 mm above system ground. The simulated as well as measured results show excellent agreement, demonstrated the suitability of the presented antenna for utilization in laptop devices for GSM 1800/WiMAX/WLAN applications [17].

Design and implementation of frequency reconfigurable antenna for wireless applications is described. This paper introduces a compact monopole antenna with dimensions of 42×16 mm². It can be reconfigured to operate in seven different bands, including, 9.2 GHz, 6 GHz, 5.5 GHz, 5 GHz, 3.5 GHz, 2.4 GHz, 1.575 GHz. The antenna design consists of three switches, operated using the positive-intrinsic-negative (PIN) diode SMP1320-079LF (Surface Mountable PIN) with a frequency range from 10 MHz to 10 GHz. The antenna's compact size makes it easy to use in devices, including laptops, tablets, and other equipment. It was simulated using computer aided design-FEKO (CADFEKO) 7.0, and in each case, the obtained reflection coefficient is well below -10 dB [18].

For WLAN applications, a miniaturized dual-band microstrip antenna is developed. This research uses electromagnetic simulation software, notably the high-frequency structure simulator (HFSS), to build two new dual-frequency microstrip antennas. The dielectric substrate used in both antennas is a common FR4 material, that provides the advantages of low costs and small size. The first antenna reduces the antenna's size by using microstrip line feeding and a folded T-shaped radiating dipole as its radiation patch. In addition, the T-shaped radiating patch has two symmetrical rectangular patches on either side of it. An additional antenna that is connected to a coaxial cable is the microstrip patch antenna. Its dimensions are minimized by integrating stepped grooves on the two patch's edges and introducing a folded slot within the patch [19].

Development and simulation of patch antenna array is presented for Wi-Fi applications at 5.4 GHz. The development and simulation of a single-band microstrip patch antenna for WLAN applications utilizing the advanced design system is shown in this work. An analysis has been conducted on a microstrip patch antenna which is configured in an array format with varying numbers of patch elements, including 1×1, 1×2, and 2×2 antenna arrays. These arrays are developed to operate in the 5.4 GHz Wi-Fi communication frequency of IEEE 802.11. The 2×2 arrays have achieved a return loss up to -40 dB at 5.4 GHz [20].

The development and execution of step-constant tapered slot antennas for the utilization of ultra wide band (UWB) is described. For UWB applications, this paper introduces the analytical approach and demonstrates the excellent performance of a step-constant tapered slot antenna (STSA). The antenna gain, return loss, level of cross polarization, and radiation pattern of this antenna are presented and analyzed. The suggested antenna provides an UWB operation from 3.1 GHz to 10.6 GHz by using a rogers (RO3006) substrate with a relative permittivity of 6.15. It has been noticed that the gain and return loss increase with the increasing step size [21].

The aim is to design an integrated tri-band antenna system with a significant frequency ratio for WLAN and wireless gigabit (WiGig) applications. This work presents the integration of a stacking patch antenna at the 2.4/5 GHz bands with a common aperture and a magnetic-electric (ME) dipole antenna operating at 60 GHz to create a novel topology. This design is based on the aperture reuse methodology and results in a reasonably high-integrated tri-band antenna system. It has good isolation and a high frequency ratio, featuring the broadside radiation patterns and identical linear polarization. A detailed prototype is constructed and tested for experimental demonstration [22].

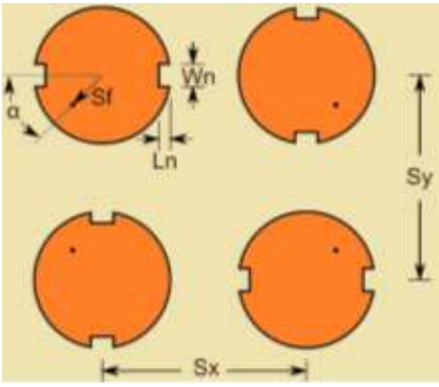
The U-shaped power quasi-isotropic antennas are designed for low-profile integration in intra-vehicle wireless communications systems. A two-port network and a two-element array model are used to demonstrate the design considerations and operational mechanisms. A more compact variant of a U-shaped $\lambda/4$ resonator is represented by the second antenna, which is a U-shaped radio frequency identification (RFID) tag antenna. When compared to their respective equivalents, the two proposed antennas exhibit the lowest recorded gain variation (GV). The structure is obtained from a simple triple-element model, and the tag may successfully achieve impedance matching that matches the terminated chip [23].

Wireless systems use a compact, symmetrical, circularly polarized, fractal boundary microstrip antenna. In order to design compact CP antennas, the indentation parameter inside the fractal boundary curve must be optimized. In relation to the two main axes (x, y), the structure exhibits asymmetry. The results of the experiment show that the suggested fractal boundary Ant 2 has a return loss of 10 dB and an axial-ratio bandwidth of 3 dB. At an operational frequency of roughly 2,540 MHz, these values are measured at 50 MHz and 162 MHz, respectively. The outcomes indicate that a single probe feed leads to excellent CP, and further decreasing the size of the antenna is achieved by applying the fractal boundary concept [24].

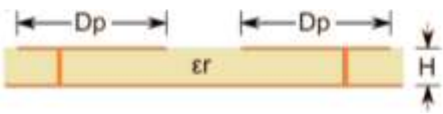
Particle swarm optimization of microstrip antennas are designed for use in wireless communication devices. The design incorporates sub-patches that are passive parasitically coupled and is described for use in the 5-6 GHz band of IEEE 802.11a WLAN. The objective of this design is to achieve an omni-directional radiation pattern, a favorable reflection coefficient, and satisfactory gain. The implementation of the design was completed, and experimental outcomes were obtained that confirm the simulations [25].

3. ANTENNA DESIGNS

In this section, cost-effective circularly polarized MIMO antenna for Wi-Fi applications is presented. The Figure 1 displays the configurations of antenna. The shape of the patch radiators is depicted in Figure 1 and is derived from a circular disk resonator. The design features a circular shape with two symmetrical cut-out perturbations, each having a specific width and depth. These perturbations stimulate two orthogonal modes with a desired 90° phase difference. FR4 substrate with H=1.6 mm thickness and 4.3 dielectric constant is used, the patches are excited via a coAR cable located at a distance a from the disk's center and at a 45°. Parameters have been fine-tuned to ensure a favorable input match and cross-polarization discrimination at 5 GHz. The 2×2 sequential-rotation array and its circular patch radiator, comprising four identical patch radiators, the sequential-rotation array undergoes sequential 90° rotations about an axis and is fed at designated points. All 2×2 sequential-rotation arrays display inherent polarization properties due to their unique symmetry. The array comprises four circular notched patches with feed pins oriented at 45° to the notch position. The geometrical dimensions are α=-45° Dp=15.98 mm, Sx=Sy=29.98 mm, Sf=2.39 mm, Wn=2.34 mm, and Ln=1.17 mm. The top view of the proposed MIMO CP antenna configuration is shown in Figure 1(a), and the side view is shown in Figure 1(b).



(a)



(b)

Figure 1. Configurations of antenna (a) configuration of the proposed MIMO CP antenna (top view) and (b) side view

4. RESULT ANALYSIS

In this section, result analysis of cost-effective circularly polarized MIMO antenna for Wi-Fi applications is described. Figure 2 illustrates the simulated input reflection coefficients, which consistently stay below -10 dB across the 4.9-5.1 GHz range. The Figure 3 shows the simulated transmission coefficients of the proposed circular antenna with different port excitations. In Figure 3, the x-axis indicates the frequency in GHz and y-axis indicates transmission coefficients in dBs.

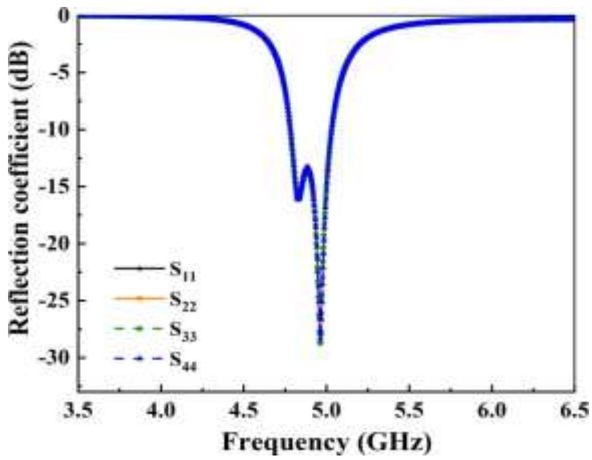


Figure 2. Simulated reflection coefficients of the proposed circular antenna with different port excitations

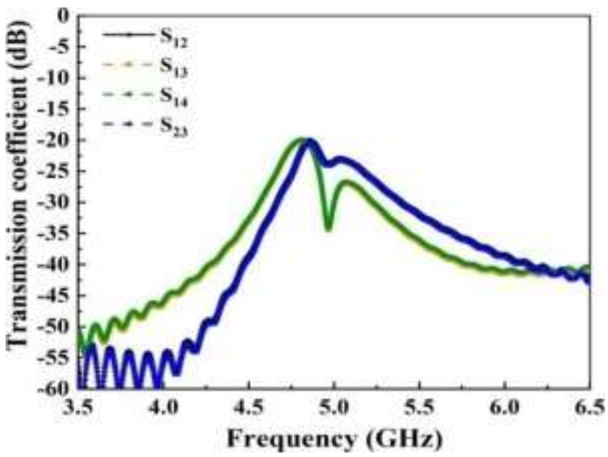


Figure 3. Simulated transmission coefficients of the proposed circular antenna with different port excitations

Figure 4 shows that AR is 1 dB achieved at 5 GHz. The Figure 5 shows the simulated electric field patterns for patch antennas. The Figure 5(a) shows the patch antenna 1, Figure 5(b) shows patch antenna 2, Figure 5(c) shows patch antenna 3, and Figure 5(d) shows patch 4 antennas simulated electric fields at 5 GHz. From Figures 5(a) to 5(d), it is observed that the four patch antennas resulted a perfectly matched impedance bandwidth and maintained good isolation between patches. Figures 6 and 7 depict the simulated radiation patterns of the designed antenna element operating at 5 GHz for different port excitations. In each scenario, the patterns consistently obtained a stable radiation pattern. Based on the simulated results, the ideal element phasing theoretically leads to perfect circular polarization in the broadside radiation. At the center frequency, a high levelof polarization purity is achieved over a wide angular range in the broadside direction. When examining radiation patterns parallel to the array axes, the angular range with a favorable AR gradually decreases on both sides of the resonant frequency. However, for the pattern at a 45° angle to the main axes, this angle decreases more rapidly. Compared to a single patch, the AR is enhanced over a broader frequency and angular range, signifying an improvement confirmed by the simulation outcomes.

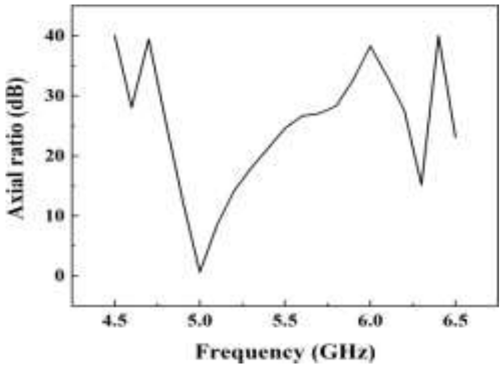


Figure 4. Simulated AR of the single circular antenna

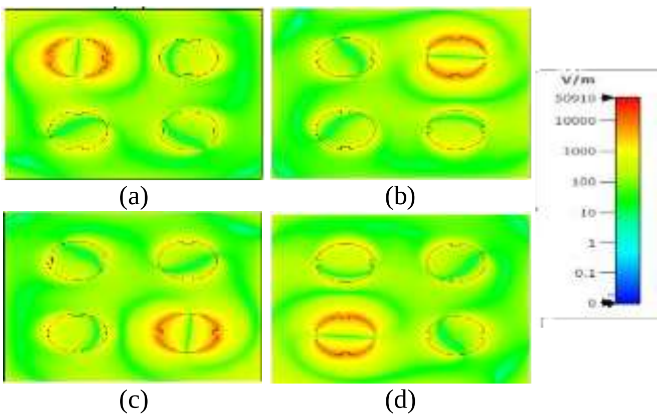


Figure 5. The simulated electric field patterns for; (a) patch 1, (b) patch 2, (c) patch 3, and (d) patch 4

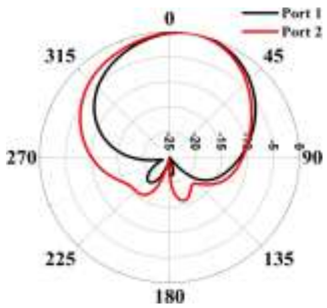


Figure 6. Simulated elevation radiation patterns for circular patch at 5 GHz

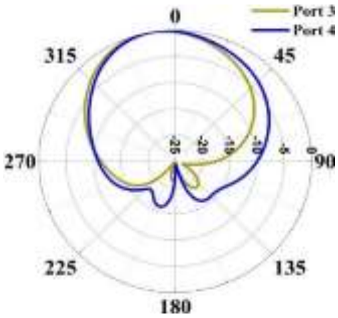


Figure 7. Simulated elevation radiation patterns for circular patch at 5 GHz

5. CONCLUSION

In this work, cost-effective circularly polarized MIMO antenna for Wi-Fi applications is presented. In summary, the study involved the construction and thorough analysis of a CP 2×2 MIMO antenna. Parameters such as S-parameters, AR, and radiation characteristics were examined. The antenna operates around 5 GHz, results a low AR of 1 dB at this frequency. With a commendable AR bandwidth of 0.2 GHz (4.9-5.1 GHz), the presented MIMO antenna emerges as economical and effective choices for Wi-Fi applications. This research underscores the potential of MIMO antennas for enhancing Wi-Fi connectivity and compactness. Particularly, the circularlypolarized 2×2 MIMO structure stands out as a robust and cost-efficient alternative among variousantenna options for Wi-Fi applications.

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