

Ultra-High Frequency Dual-Polarized Microstrip Patch Antennas for TV White Space Applications

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Abstract—The increasing demand for wireless communication highlights the relevance of ultra-high frequency (UHF) systems, particularly for TV white space (TVWS) applications. However, existing designs struggle to simultaneously achieve compact size, dual-band operation, and high-isolation Multiple-Input Multiple-Output (MIMO) performance. This work proposes two dual-polarized microstrip patch antennas (DP-MPAs) operating at 560 MHz and 680 MHz, enabling a 2×2 MIMO configuration via orthogonal polarization. Full-wave simulations show reflection coefficients below -10 dB, bandwidths exceeding 24 MHz, and isolation better than -20 dB, with 2 dBi realized gain. The design offers an efficient and compact solution for UHF MIMO TVWS systems.

Keywords—UHF, microstrip patch antennas, TVWS, MIMO, orthogonal polarization modes.

I. INTRODUCTION

The increasing demand for reliable wireless communication has intensified the exploration of the ultra-high frequency (UHF) spectrum, particularly within the context of television white space (TVWS) applications [1]–[4]. Owing to their favorable propagation characteristics, such as extended coverage and improved penetration through obstacles, UHF signals are especially suitable for rural, industrial, and mission-critical scenarios [5]–[7]. As a result, UHF-based technologies have emerged as a promising enabler for next-generation wireless systems requiring robust, energy-efficient, and wide-area connectivity [8], [9]. Despite these advantages, the realization of compact and efficient antennas operating at UHF frequencies remains a fundamental challenge. In particular, microstrip patch antennas (MPAs), widely favored for their low profile, ease of fabrication, and compatibility with planar platforms, inherently suffer from large physical dimensions at low frequencies due to their wavelength-dependent resonant behavior. This limitation

significantly constrains their integration into compact and embedded systems, motivating extensive research into antenna miniaturization techniques.

A variety of strategies have been proposed to overcome this limitation. One major class of approaches focuses on radiating element engineering, including meandered geometries [10], [11], slot loading [12], [13], material loading [14], [15], and structural perturbations [16], all aiming to increase the effective electrical length without enlarging the physical footprint. Another line of research explores ground-plane modifications, such as truncated [17] and defected structures [18], [19], to enhance impedance matching and bandwidth. More recently, electromagnetic-based approaches, including distributed reactive loading and periodic structures [20], [21], have enabled improved control of surface current distributions and radiation characteristics.

In parallel, modern wireless systems increasingly rely on Multiple-Input Multiple-Output (MIMO) technology to improve spectral efficiency and link reliability. However, integrating MIMO capabilities into compact UHF antennas introduces additional challenges, particularly in terms of mutual coupling and envelope correlation. Conventional decoupling techniques often depend on large inter-element spacing, which directly conflicts with miniaturization requirements. To address this trade-off, polarization diversity (achieved through the excitation of orthogonal modes) has emerged as an effective alternative for ensuring high isolation within a reduced footprint [22]–[25].

However the simultaneous achievement of compact size, dual-band operation in the UHF TVWS range, and high-isolation MIMO performance within a single planar-based platform is still insufficiently addressed in the literature. Existing designs typically optimize only a subset of these requirements, limiting their applicability in practical communication systems. To address this challenge, this work proposes two compact dual-polarized MPAs (DP-MPAs) operating at 560 MHz and 680 MHz, specifically targeting Frequency Division Duplexing (FDD) solutions for TVWS and long-range communication applications such as described in [26], [27]. The proposed design combines miniaturization techniques with a dual-polarized architecture inspired by [25], enabling the implementation of a 2×2 MIMO system through orthogonal polarization modes. This approach eliminates the need for increased spatial separation while maintaining high isolation between antenna elements. The antennas are implemented using planar fabrication techniques and optimized radiating and feeding structures. Full-wave simulations demonstrate that the proposed designs achieve reflection coefficients below -10 dB in their respective operating bands, with impedance

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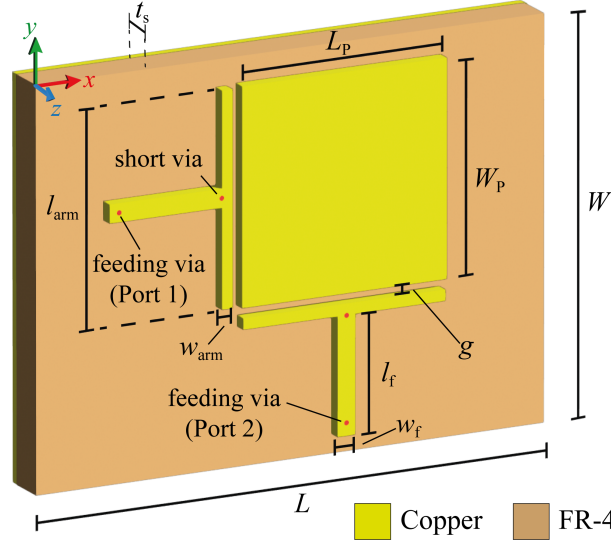


Fig. 1: Schematic representation of the DP-MPA and the geometric parameters.

bandwidths exceeding 24 MHz. Furthermore, the MIMO configuration provides inter-port isolation better than -20 dB, confirming the effectiveness of polarization diversity for mutual coupling reduction. The antenna also exhibits stable radiation characteristics, with realized gains of approximately 2 dBi and high radiation efficiency across both frequency bands. Overall, the proposed solution provides a compact, low-cost, and efficient platform for UHF MIMO systems, contributing to the advancement of TVWS-based communication technologies and enabling reliable connectivity in next-generation wireless networks.

II. DESIGN AND METHODS

Figure 1 illustrates the geometry of the proposed UHF DP-MPA. The structure is composed of two main material layers: a metallic layer (yellow), corresponding to copper, and a dielectric substrate (brown), corresponding to an FR-4 laminate. The bottom metallic layer forms the ground layer, while the top copper layer comprises the radiating element and the vertical (y -pol) and horizontal (x -pol) feeding networks.

A key feature of the proposed design is the implementation of a 2×2 MIMO configuration through the excitation of orthogonal polarization modes. This is achieved by employing two independent feeding ports (Port 1 and Port 2) oriented such that they excite distinct current distributions along orthogonal axes of the structure, with each port exclusively exciting one of the orthogonal modes. As a result, the antenna supports horizontal and vertical polarization modes, enabling intrinsic isolation between ports without requiring large physical separation. This approach significantly reduces mutual coupling and enhances MIMO performance while preserving compactness.

The overall dimensions of the substrate are defined by its length L , width W , and thickness t_s . A rectangular radiating patch is printed on the top surface of the substrate, characterized by its length L_P and width W_P . A small gap g separates the patch from the feeding structures, which plays a key role in controlling the coupling level and input impedance. The

feeding networks consist of a microstrip line with length l_f and width w_f , which excites the structure through the feeding vias connecting the antenna to a SMA connectors beneath the DP-MPA. Additionally, a half-like dipole arms with length l_{arm} and width w_{arm} are incorporated to enhance the current distribution and tuning capability of the antenna. The structure also includes short vias that provides an additional conductive path, enabling further control of the resonance characteristics.

The proposed DP-MPAs were designed and optimized using full-wave electromagnetic simulations performed in CST Studio Suite. All metallic layers (including vias) were modeled as finite-conductivity copper with $\sigma = 5.8 \times 10^7$ S/m and a typical thickness of $35 \mu\text{m}$. The FR-4 substrate was modeled as a lossy dielectric with relative permittivity $\epsilon_r = 4.3$ and loss tangent $\tan \delta = 0.025$.

After the coarse sizing of all geometric parameters (to set the working frequency around the intended ranges), the entire geometry was parameterized in a systematic optimization through automatic parametric sweeps within CST, using the resonance frequencies range as target. For both DP-MPAs, the targets were set in a central frequencies of 560 MHz and 680 MHz, with a minimum -10 dB bandwidth of 24 MHz each, to ensure a well operation in Anatel's licensed UHF frequencies. Open (add space) boundary conditions were employed to emulate free-space radiation, and the antennas were excited using waveguide ports through two SMA connectors placed beneath each antenna, with Port 1 associated with the x -pol and Port 2 with the y -pol. Analysis were performed between $500 \leq f \leq 750$ MHz in terms of return loss, mutual coupling, field distribution, and directivity, gain, and realized gain.

III. RESULTS AND DISCUSSION

The final structure was designed to operate at distinct frequency bands centered at 560 MHz (DP-MPA 1) and 680 MHz (DP-MPA 2), with a minimum bandwidth requirement of 24 MHz. For this, two separate antennas were optimized for each band, resulting in two compact structures with reduced

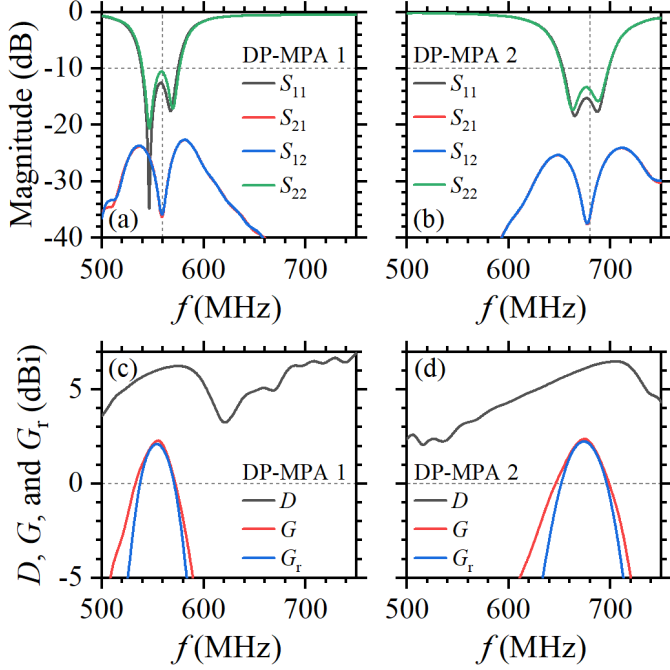


Fig. 2: S-parameter magnitudes in dB for UHF (a) DP-MPA 1 and (b) DP-MPA 2. D (black), G (red), and G_r (blue) for UHF (c) DP-MPA 1 and (d) DP-MPA 2.

dimensions of $227 \times 304 \text{ mm}^2$ for the DP-MPA 1 design and $200 \times 300 \text{ mm}^2$ for the DP-MPA 2 design. The optimized geometric parameters for each DP-MPA is depicted in Table I.

The simulated scattering parameters S demonstrate in Fig. 2 that the proposed DP-MPA achieves satisfactory impedance matching in both operating bands. Specifically for the DP-MPA 1 design at 560 MHz (Figure 1(a)), the reflection coefficients S_{11} (black) and S_{22} (green) associated with both orthogonal polarization excitation (x -pol and y -pol) exhibit pronounced minima near the target frequency, with values below -10 dB threshold (gray-dashed line) across the desired bandwidth. Similarly, the antenna designed for DP-MPA 2 design at 680 MHz (Figure 1(b)) presents adequate matching performance, with reflection coefficients remaining below the -10 dB within the specified frequency range. In both cases,

TABLE I: Geometric parameters for DP-MPAs.

DP-MPA 1 – 560 MHz		DP-MPA 2 – 680 MHz	
Parameters	Dimension (mm)	Parameters	Dimensions (mm)
L	304.00	L	300.00
W	227.00	W	200.00
L_P	122.57	L_P	99.97
W_P	122.57	W_P	99.97
l_{arm}	121.13	l_{arm}	90.34
w_{arm}	6.40	w_{arm}	8.09
l_f	66.96	l_f	43.36
w_f	10.55	w_f	8.73
g	5.57	g	5.48

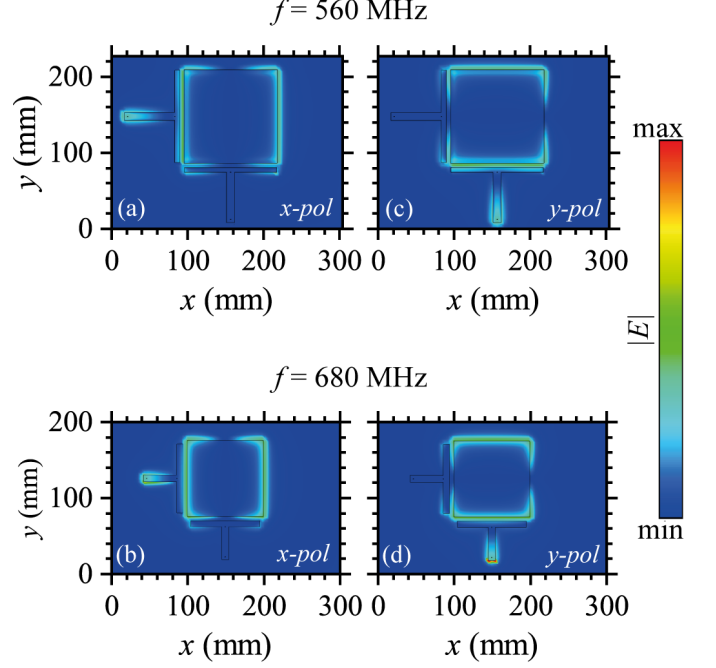


Fig. 3: Normalized E near-field at resonance in (a)-(b) 560 MHz and (c)-(d) 680 MHz for excitation of orthogonal fundamental modes x -pol (left-side) and y -pol (right-side).

the achieved bandwidth exceeds the minimum requirement of 24 MHz, confirming the effectiveness of the design approach for UHF. The mutual coupling between ports was also evaluated through the transmission coefficients S_{12} (blue) and S_{21} (red). The results indicate that the coupling remains below -20 dB for both antennas across the bands of interest of each. These values demonstrate high isolation between the ports, which is particularly remarkable given the compact nature of the structure. The low coupling levels can be directly attributed to the orthogonality of the excited polarization modes (x -pol and y -pol), which inherently reduces electromagnetic interaction between the ports.

The radiation characteristics of the antenna were analyzed in Fig. 2(c)-(d) in terms of directivity D (black), gain G (red), and realized gain G_r (blue). We should remark that the presented values consider a single polarization metric performance for each DP-MPA (x -pol), but the results can be extended for y -pol case, mainly associated with the symmetric-like system. The results show that the antennas exhibits a moderately directive radiation pattern, with D values ranging from approximately 5 to 6.5 dBi across the operating bands. G reaches values close to 2 dBi at the resonance frequencies, while the realized gain closely follows the gain curve, indicating efficient impedance matching and minimal mismatch losses. The difference between D and G reflects the intrinsic losses associated with the high losses dielectric substrate considered, while the agreement between gain and realized gain confirms effective power transfer.

Fig. 3 provides a further insight into the antennas operation by the analysis of the electric near-field distributions. The results in Figs. 3(a)-(b) clearly show that, under horizontal

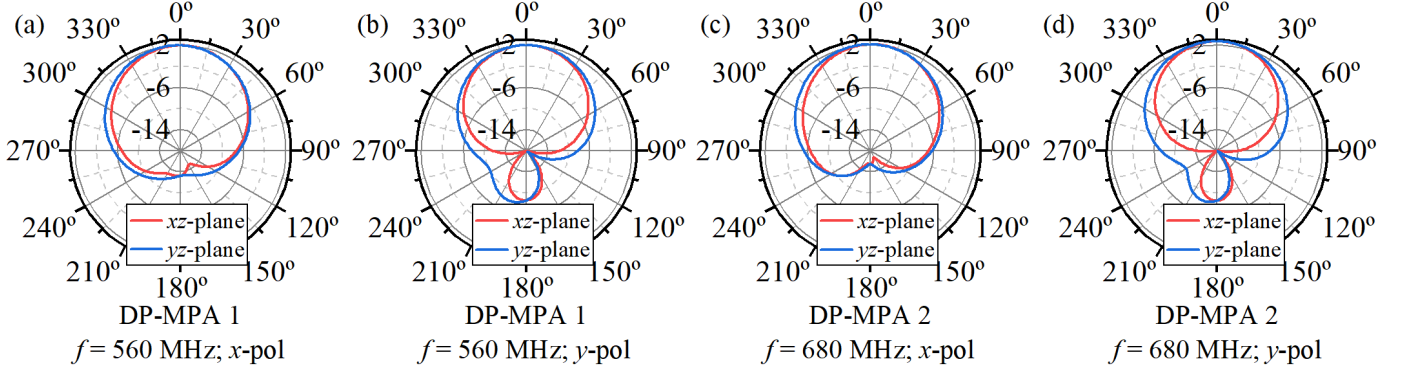


Fig. 4: Realized gain radiation patterns in xz (red) and yz (blue) planes for (a) DP-MPA 1 under x -pol, (b) DP-MPA 1 under y -pol, (c) DP-MPA 2 under x -pol, and (d) DP-MPA 2 under y -pol, with maximum $G_r \approx 2$ dBi at $\theta = 0^\circ$ direction.

excitation (x -pol), the electric field is predominantly distributed along the horizontal sections of the radiating patch structure, indicating the excitation of a mode aligned with the x -axis. Conversely, under vertical excitation (y -pol), the electric field in Figs. 3(c)-(d) is concentrated along the vertical sections, corresponding to a mode aligned with the y -axis. This distinct separation of field distributions confirms the excitation of orthogonal polarization modes and explains the low mutual coupling observed in the S -parameter results in Fig. 2. From a system perspective, the combination of high isolation and orthogonal polarization leads to low correlation between MIMO channels, which is essential for achieving high diversity gain and increased channel capacity. The proposed antenna therefore meets the key requirements for MIMO operation in UHF communication systems, particularly in TVWS applications where spectral efficiency and link robustness are critical.

Figure 4 presents the realized gain radiation patterns of the proposed DP-MPA 1 and DP-MPA 2 in the principal planes. The results are shown for both orthogonal excitations at their respective operating frequencies. Specifically, in Fig. 4(a) is shown the radiation characteristics in the xz - and yz -planes of DP-MPA 1 at $f = 560$ MHz under x -polarized excitation. The antenna exhibits a broadside radiation pattern with a well-defined main lobe centered at $\theta = 0^\circ$, indicating efficient radiation normal to the patch surface. The patterns in both planes are relatively symmetrical, with minor deviations attributed to the asymmetry introduced by the feeding structure and shorting vias. The back radiation is significantly suppressed, confirming the effectiveness of the ground plane. Figure 4(b) shows the corresponding patterns for DP-MPA 1 under y -polarized excitation at the same frequency. A similar broadside behavior is observed. However, slight differences between the xz - and yz -plane patterns can be noted, particularly in the back lobe region. These variations are expected due to the current distribution excited on the patch, which modifies the radiation mechanism and field distribution. On the other hand, Figs. 4(c)-(d) present the radiation patterns for DP-MPA 2 at $f = 680$ MHz for x -pol and y -pol, respectively. In particular, Fig. 4(c) the antenna presents a stable broadside radiation with good symmetry in both principal planes. Similarly, Fig. 4(d) shows consistent radiation behavior under y -pol excitation, although a slightly more pronounced asymmetry and back lobe

can be observed compared to the x -pol case.

Overall, the results indicate that both antenna configurations preserve stable radiation characteristics across the operating frequencies and for both polarizations. The main lobes are consistently directed toward broadside, with moderate beamwidth and controlled back radiation. The small discrepancies between the xz - and yz -plane patterns highlight the impact of the feeding network and structural asymmetries, which is typical in practical dual-polarized designs. From a system perspective, despite lower G_R (~ 2 dBi) compared with D (~ 6 dBi), these results confirm that the proposed antennas are suitable for portable and indoor TVWS applications requiring polarization diversity, as they provide comparable radiation performance for orthogonal excitations. The stable gain patterns and consistent broadside radiation across frequencies suggest reliable coverage and minimal polarization-dependent performance degradation, which are critical for modern wireless communication systems, including MIMO and diversity schemes.

IV. CONCLUSIONS

This paper presented two designs of DP-MPAs capable of supporting efficient 2×2 MIMO operation in the UHF band. The proposed design combined geometric miniaturization techniques, engineered ground-plane modifications, and optimized feeding structures, together with polarization diversity through orthogonal mode excitation. This integrated approach enabled the realization of a compact antenna platform without relying on large spatial separation between elements. The obtained results demonstrated dual-band operation at 560 MHz and 680 MHz, with impedance bandwidths exceeding 24 MHz, reflection coefficients below -10 dB, and inter-port isolation better than -20 dB. In addition, the antenna exhibited stable radiation characteristics, with realized gains around 2 dBi and high radiation efficiency, confirming its suitability for portable and indoor TVWS applications. The field distribution analysis further validated the excitation of orthogonal modes, ensuring effective MIMO performance. These findings indicate that the proposed DP-MPAs provide a compact, low-cost, and efficient solution that simultaneously addresses key limitations of existing UHF planar antenna designs. Therefore, this work contributes to the advancement of practical UHF MIMO systems and offers a promising

pathway for the implementation of TVWS-based wireless communication networks, with potential for future extensions involving reconfigurability and adaptive spectrum utilization.

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