

DESIGN AND ANALYSIS OF AN ASYMMETRIC CPW-FED 1×2 MIMO ANTENNA SUPPORTING FIVE DISTINCT FREQUENCY BANDS FOR MULTISTANDARD WIRELESS COMMUNICATION

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Abstract

This paper presents the design and development of an asymmetric coplanar waveguide (CPW) fed 1×2 MIMO multiband antenna system for modern wireless communication applications. The proposed design aims to achieve enhanced operating gain and impedance matching while catering to the stringent requirements of the advanced communication systems. Through a comprehensive simulation-based approach, the performance of the 1×2 asymmetric CPW-fed MIMO antenna is evaluated, considering key metrics such as return loss, bandwidth, radiation characteristics, and performance parameters. The designed antenna system demonstrates promising results with penta-band operating characteristics, showcasing its potential for fulfilling the demands of high-speed and reliable wireless communication applications like 5G and X-band Radar. The Envelope Correlation Coefficient (ECC) values of the antenna range from 0.00034 to 0.008, and the Diversity Gain (DG) is around 9.99% with a TARC of 0.260.

Keywords: 1×2 MIMO antenna, 5G Applications, Asymmetric CPW feed, ECC, High isolation and high gain MIMO antenna, Penta-band antenna.

1. Introduction

A component that plays a major role and occupies a critical position in wireless communication systems is the antenna, which acts as an interface for guiding radiated electromagnetic energy [1]. The demand for antennas with features such as compact size, higher gain, and efficient operational characteristics is increasing with the drastic development in the field of wireless technologies, ranging from mobile networks and satellite systems to radar and the Internet of Things (IoT). Consequently, the modern radiating device is expected to provide services for multiple communication standards; thus, the design and development of multiband operating antennas have gained significant attention. Multiband antennas are preferred over single-band antennas as they are suitable candidates for reducing the size, cost, and complexity involved in traditional wireless communication systems. Thus, a single antenna serving different applications is the need of the day, and this research focuses on designing one such antenna suitable for modern wireless communication standards, ranging from 5G to X-band applications.

In contemporary discourse, Fifth Generation (5G) technology has garnered substantial attention within wireless communication. 5G networks stand out as a promising candidate for wireless connectivity due to their extraordinary data transmission rates, reduced delays, and increased spectral efficiency. In response to these requirements, the 5G wireless communication standard has emerged as a pivotal force, with the potential to transform various sectors, including telecommunications, healthcare, transportation, and the development of smart cities. These dynamic benchmarks demand RF engineers to design and develop antennas incorporating recent technological advancements such as metamaterial unit-cell-loaded antennas, hybrid arrays, and MIMO antennas. At the foundation of the modern telecommunications framework lies the principle of Multiple Input Multiple Output (MIMO) technology, which employs an array of antennas at both the transmission and reception endpoints to significantly enhance spectral efficiency, data throughput, and overall system capacity. Caroline et al. [2] illustrated that MIMO systems leverage spatial diversity and multipath propagation to enable resilient and reliable communication across a spectrum of intricate environments. Within the domain of MIMO systems, the advancement of efficient and compact antenna configurations is essential for achieving the desired performance metrics. In this context, CST Studio Suite software is employed for electromagnetic simulation, three-dimensional modelling, and visualization. This manuscript delineates the design and analytical evaluation of an asymmetric CPW-fed multiband MIMO antenna. The proposed antenna configuration aspires to meet the stringent specifications of advanced wireless communication systems, encompassing wide bandwidth, elevated gain, and minimal correlation.

2. Related Works

Ahmad et al. [3] presented a compact CPW-fed ultra-wideband (UWB) multi-input multi-output (MIMO) antenna designed for applications within wireless communication networks. The antenna has been meticulously engineered to function across an expansive frequency spectrum, thereby facilitating compatibility with diverse wireless communication standards, while concurrently offering multiple input and output functionalities to enhance performance metrics such as data rate, reliability, and coverage. Numerous significant advancements have been documented within this area, which seek to tackle the myriad challenges and

demands presented by contemporary communication frameworks. Nonetheless, additional enhancements are necessary to augment bandwidth and minimize antenna dimensions, thereby fostering more compact and adaptable integration into modern communication apparatuses. A pivotal contribution to this field is the research conducted by Cheng and Du [4], which unveiled a low-profile wideband square patch antenna with four-corner feeding specifically for MIMO mobile applications. The antenna design successfully attained a broad impedance bandwidth encompassing the complete frequency spectrum designated for 5G communication, while preserving a compact physical profile suitable for incorporation into mobile devices. The proposed antenna exhibited outstanding radiation characteristics, including elevated gain, reduced cross-polarization, and substantial isolation among antenna elements, establishing it as a promising candidate for wireless MIMO systems.

A significant contribution to this domain is the research conducted by Chen et al. [5], which proposed a wideband PIFA pair-based MIMO antenna design optimized for seamless integration into smartphones. The suggested antenna design capitalized on the compact form factor of PIFA structures while integrating innovative methodologies to achieve wideband functionality and minimize mutual coupling among antenna elements. Empirical findings substantiated the efficacy of the proposed antenna in delivering high data rates and dependable connectivity for applications within smartphones. The experimental validation of the antenna in real-world applications illustrated its potential for practical deployment in next-generation smartphones. Although notable advancements have been achieved in the development of wideband PIFA pair-based MIMO antennas intended for 5G smartphones, ongoing research endeavours remain directed towards further refining antenna performance concerning bandwidth, efficiency, and compatibility with emerging 5G communication standards. Saadh et al. [6] explored a uniquely shaped MIMO antenna constructed from FR4 material to enhance isolation and bandwidth for wireless applications. This study elucidates the progression of a quad-element ultra-wideband (UWB) MIMO antenna characterized by enhanced isolation and gain. The antenna employs innovative decoupling networks that significantly augments both isolation and gain. The incorporation of Luna-shaped radiators along with a compact design renders it suitable for small wireless devices.

Patchala et al. [7] introduced a compact MIMO antenna characterized by a triple-band notch, which incorporates a defective ground structure alongside a split ring resonator, aimed at facilitating broad-spectrum applications. The utilization of multiple antennas at both the transmission and reception junctures is paramount in augmenting the efficacy of communication systems. It is imperative to ensure the seamless integration of the antenna within portable devices while upholding established performance benchmarks. Dey et al. [8] expounded upon the empirical investigation of a novel compact and flexible super-wideband antenna specifically engineered for 5G applications. This scholarly article elucidates the design, fabrication, and empirical evaluation of an avant-garde compact and flexible super-wideband antenna that has been meticulously optimized for 5G applications. The antenna is designed to operate across an expansive frequency spectrum, thereby accommodating the multitude of frequency bands utilized within 5G networks. Karthikeya et al. [9] analysed a CPW-fed wideband corner bent antenna that is appropriate for 5G mobile terminals. The selection of a CPW-fed wideband corner

bent antenna is a prudent choice for 5G mobile terminals, given its compact form factor, extensive bandwidth, and potential for omnidirectional radiation patterns.

Magray et al. [10] elucidate wideband asymmetric coplanar strip-fed antennas featuring pattern diversity, which present an effective solution for millimeter-wave 5G base stations, offering superior performance, adaptability, and cost efficiency for next-generation wireless communication systems. Mak et al. [11] introduced a 5G wideband patch antenna equipped with antisymmetric L-shaped probe feeds. A 5G wideband patch antenna with antisymmetric L-shaped probe feeds provides a compact, low-profile, and economically viable solution characterized by high gain, enhanced radiation patterns, and polarization diversity, thereby making it exceptionally suited for next-generation 5G communication systems. Sehrai et al. [12] investigate a novel high-gain wideband MIMO antenna for 5G millimeter-wave applications. The design of a novel high-gain wideband MIMO (Multiple Input Multiple Output) antenna for 5G millimeter-wave applications necessitates meticulous consideration of various factors, including frequency band, antenna dimensions, radiation pattern, polarization, and isolation between antenna elements. Singhal [13] proposed a feather-shaped super-wideband MIMO antenna. The design of a feather-shaped super wideband MIMO antenna entails the incorporation of innovative geometric features and advanced design methodologies to achieve wideband functionality, high gain, and multiple-input multiple-output (MIMO) capabilities.

Wong et al. [14] introduce a low-profile wideband four-corner-fed square patch antenna specifically designed for 5G MIMO mobile antenna applications. The formulation of a low-profile wideband four-corner-fed square patch antenna intended for 5G MIMO mobile antenna applications requires meticulous examination of the antenna's geometric configuration, feeding technique, impedance alignment, and radiative properties. Yuan et al. [15] proposed a wideband PIFA-pair-based MIMO antenna explicitly intended for 5G smartphones. The advancement of a wideband PIFA (Planar Inverted-F Antenna) pair-based MIMO antenna aimed at 5G smartphones necessitates the amalgamation of multiple PIFA components near facilitate MIMO functionalities while concurrently ensuring wideband performance to accommodate the frequency ranges pertinent to 5G technology. Designs like CPW-fed patches, defected ground structures (DGS), metamaterial-loaded antennas, and fractal geometries are examples of recent research on 1×2 MIMO antenna topologies. For improved isolation and wideband performance, CPW-fed and DGS-based antennas are frequently utilized. Designs inspired by metamaterials enhance miniaturization and gain, and fractal shapes facilitate multiband operation. However, efficiency, compactness, or consistent MIMO metrics like DG and ECC are trade-offs for many designs. These findings emphasize the necessity of topologies that balance MIMO performance, size, and bandwidth. Thus, in the presented research, the asymmetric CPW feed along with the use of slots for the creation of a multiband is preferred.

3. Materials and Methods

In the presented antenna, the choice of substrate material FR-4 depends on factors such as dielectric constant (permittivity), loss tangent, temperature stability, and cost [16]. The CPW serves as the feeding mechanism, wherein the side-plane conductor operates as the ground while the central strip is responsible for signal transmission. A notable advantage of a CPW-fed slot antenna lies in its broad

bandwidth capabilities. Asymmetric CPW-fed antennas have attracted considerable scholarly interest owing to their extensive bandwidth, compact dimensions, ease of integration, and compatibility with an array of substrate materials. Thus, in the presented antenna research, the CPW feed is designed as an asymmetric feed structure. The asymmetry is obtained by placing a different-width side plane conductor differing by 0.5 mm. The initial radiator is square with $80 \times 80 \text{ mm}^2$ in size. The measurement of the substrate is $160 \times 160 \text{ mm}^2$. The visual presentation of the initial radiator is available in Fig. 1.

In order to guarantee optimal performance across the targeted frequency bands, the parameter optimization process was methodically completed during the early phases of antenna design. The feed line width, the ground plane dimensions, and the radiating patch's length and width were among the important design parameters that were subject to change. The antenna's radiation characteristics, bandwidth, return loss, and impedance matching are all greatly impacted by these parameters. With the help of the built-in CST Microwave Studio® optimizer tool, ten iterations were carried out for each parameter with a step size of one unit in order to obtain the optimal configuration. Critical performance metrics like return loss (S_{11}), gain, and impedance bandwidth were used to monitor and assess the simulation outputs during each iteration. According to the current design, the finalized dimensions reflect the best possible balance between the three main trade-offs: maximizing gain, minimizing return loss, and providing sufficient bandwidth throughout the operating range.

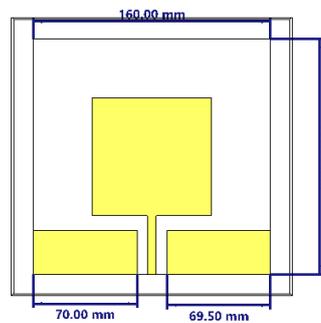


Fig. 1. Initial asymmetric CPW-fed single antenna design.

During the design evaluation phase, even the substrate material was changed, including the use of high-performance substrates like Rogers AD400. Nevertheless, it was found that the antenna had comparatively low gain and uneven impedance matching throughout the targeted frequency bands, even though the Rogers AD400 had a lower loss tangent and a higher dielectric stability. On the other hand, when combined with the CPW (Coplanar Waveguide) feeding technique, the FR4 substrate showed better performance in terms of gain, radiation efficiency, and return loss, despite generally being linked to higher dielectric losses. Effective impedance matching and field confinement made possible by the CPW structure on the FR4 substrate are responsible for this enhanced performance. The designed initial square antenna's intended operating bands are from 1 to 20 GHz. The designed radiator offers single-band resonance across 1.14 to 3.21 GHz, resonating at 1.54 GHz as its fundamental resonance frequency and the operating bandwidth is 207 MHz with the return loss of -35 dB. The radiation efficiency is above 89 %.

The realized gain value is 2.32 dBi. The scattering characteristics, when observed, show some minimal resonance at other higher-order frequencies; thus, to further enhance the operating bands, the single antenna is converted into a 1x2 MIMO antenna in the next design stage as depicted in Fig. 2. The resultant antenna radiates across dual bands, at a higher order 6.93 to 7.12 GHz frequency with the return loss of -15 dB, along with the slightly shifted fundamental frequency at 2.34 to 3.89 GHz with the return loss of -34 dB.

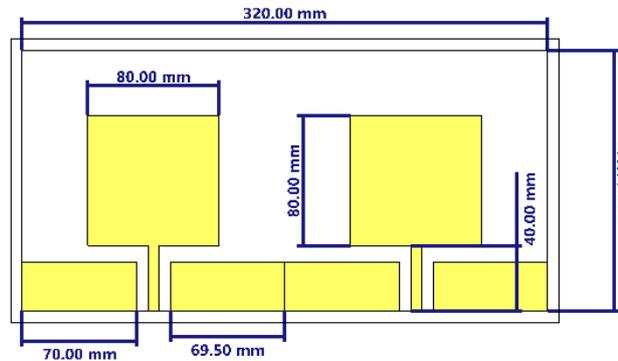


Fig. 2. Asymmetric CPW-fed 1×2 MIMO antenna design.

Throughout the design process, it's important to iteratively refine the antenna design based on simulation results. Thus, the initial antenna is modified structurally to fit in to operate as a multiband antenna. The work comprises of antenna under consideration that comprises a modified trapezoidal shape that incorporates an extended L-shaped strip, which is interconnected to the ground plane. The rectangular slot measuring 60 x 20 mm² is precisely placed at the centre of the patch, which in turn improves the number of operating bands. Figure 3 depicts the pictorial view of the proposed trapezoidal asymmetric CPW-fed 1×2 MIMO antenna. By leveraging the extended strip, there is a significant enhancement in the axial ratio within the lower frequency band.

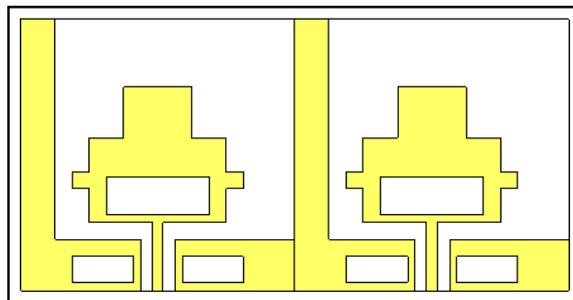


Fig. 3. Trapezoidal asymmetric CPW - fed MIMO (1×2) antenna design.

4. Results and Discussion

The return loss can be determined utilizing the following equation:

$$\text{Return Loss (in dB)} = -20 * \log_{10} (|S_{11}|) \quad (1)$$

where Return Loss is expressed in decibels (dB). S_{11} and S_{22} are the reflection coefficient, which denotes the proportion of reflected signal power of the incident signal power from antennas 1 and 2.

Figure 4 depicts the Scattering characteristics (S_{11} and S_{22}) obtained for the Trapezoidal asymmetric CPW-fed 1×2 MIMO antenna. It can be observed from the visualization that a total of five resonance bands are obtained. The operating bands are 3.01 - 3.46 GHz, 6.74 - 7.19 GHz, 10.56 - 11.14 GHz, 14.17 - 14.60 GHz, and 17.63 - 18.05 GHz. The resultant impedance bandwidth values range from 420 to 580 MHz.

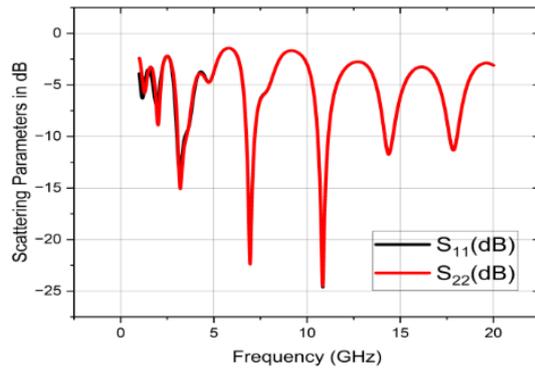


Fig. 4. Scattering parameters of 1×2 MIMO antenna.

VSWR, an acronym for “Voltage Standing Wave Ratio,” represents a critical metric employed within the domains of radio frequency (RF) engineering and telecommunications for evaluating the efficacy of power transmission along a transmission line, cable, or antenna as shown in Figs. 5 and 6. present the visual representation of the VSWR of the designed trapezoidal asymmetric CPW-fed 1×2 MIMO antennas 1 and 2, respectively. The values of VSWR that are realized by the designed antenna are well within the nominal value of 2.

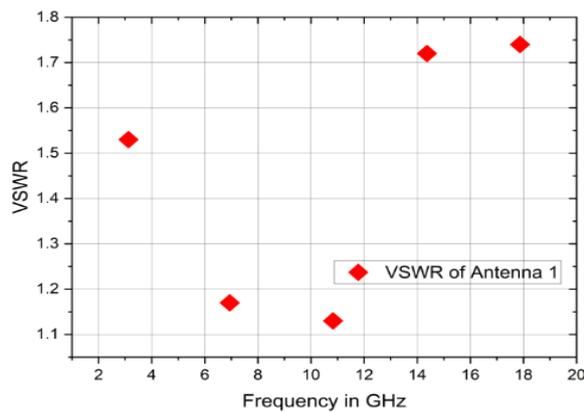


Fig. 5. VSWR of the 1×2 MIMO antenna 1.

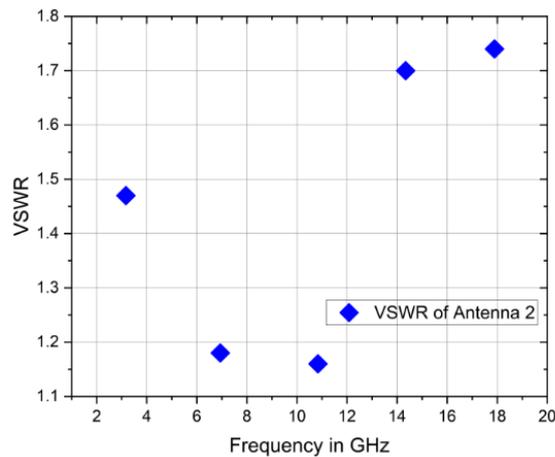


Fig. 6. VSWR of the 1×2 MIMO antenna 2.

The designed 1×2 MIMO antenna 1’s gain performance has been evaluated across its five operational frequencies and visualized in Fig. 7. The observed peak gain values are 5.51, 6.97, 5.75, 6.76, and 6.45 dBi, respectively. Similarly, the 1×2 MIMO antenna 1’s gain values were 5.21, 6.7, 6.08, 6.48, 6.39 dBi as depicted in Fig. 8. The gain values realized highlight that the designed antenna reveals constant high gain characteristics, vital for attaining efficient radiation characteristics in the advanced wireless communication systems. The peak gain values at all the operating bands are consistently above 5 dBi, and this defines the suitability of the designed trapezoidal asymmetric CPW-fed multiband antenna for high frequency applications like 5G, WLAN, X-Band Radar and IoT-based systems. The radiation pattern of an antenna characterizes the fluctuation in power emitted by the antenna as a function of the orientation relative to the antenna. At the operating frequencies as visualized in Fig. 9, the designed antenna displays a sturdy and intensive radiation profile with worthy main lobe features and rational side lobe control, making it a possible choice for application in directive advanced communication systems. The pattern visualized indicates that the radiation is oriented directionally rather than an omnidirectional pattern.

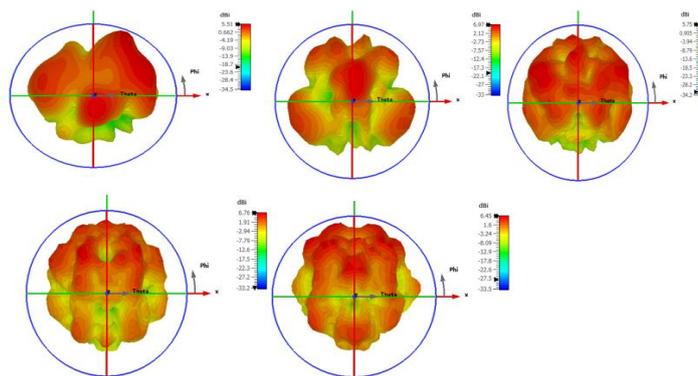


Fig. 7. Gain of antenna 1 at 3.13 GHz, 6.94 GHz, 10.83 GHz, 14.37 GHz, 17.87 GHz.

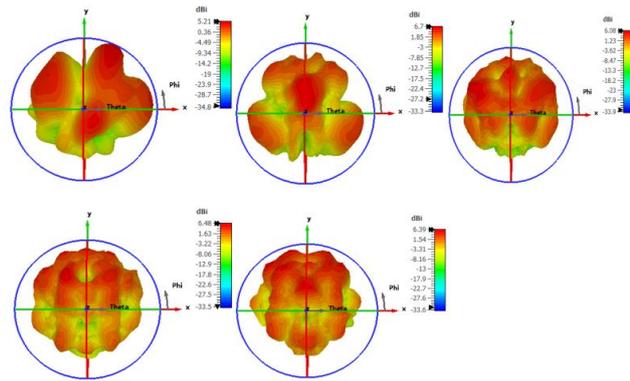


Fig. 8. Gain of antenna 2 at 3.17 GHz, 6.94 GHz, 10.84 GHz, 14.34 GHz, 17.89 GHz.

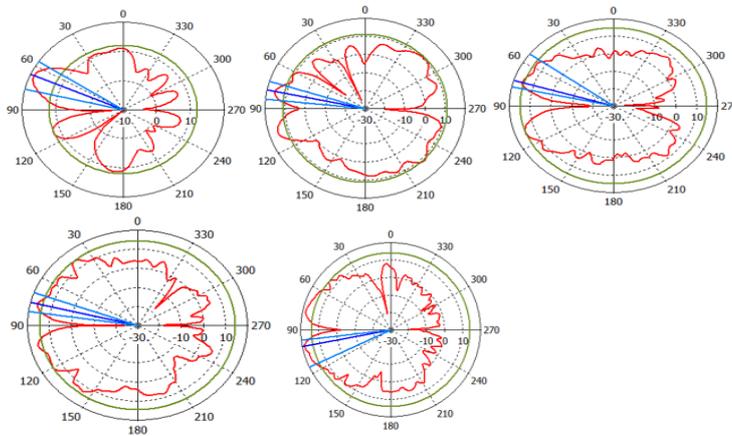


Fig. 9. E-fields of Antenna 1 at 3.13 GHz, 6.94 GHz, 10.83 GHz, 14.37 GHz, and 17.87 GHz.

The surface current distribution across the radiating structure at its respective operating frequencies displays substantial magnitude variations, with peak surface current densities documented as 48.5 A/m, 47.8 A/m, 56.6 A/m, 54.3 A/m, and 53.5 A/m. The sample surface current distribution of Antenna 1 and 2 at 3.13 GHz is visualized in Fig. 10. The radiation efficiency is a ratio that reflects the total power radiated by an antenna compared to the total input power received from the generator. The designed asymmetric CPW-fed 1×2 MIMO antenna exhibits excellent average Radiation Efficiency of 98.25% for Antenna 1 and 98.38% for Antenna 2. These attained radiation efficiencies outline that the designed antenna has effectively radiated all the power. Further, the total radiation efficiency, which accounts for the radiation and mismatch losses, is observed to be 75.93% and 74.15%. These results indicate that the designed asymmetric CPW-fed 1×2 MIMO antenna maintains the good overall radiation performance, which makes it an ideal radiator for application in high frequencies.

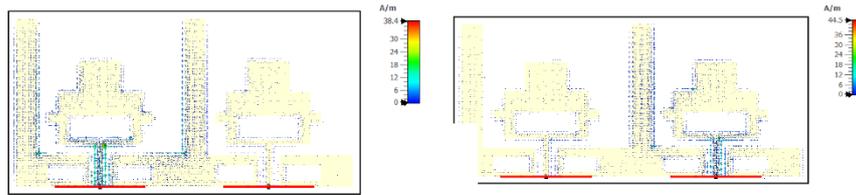


Fig. 10. Sample surface current distribution of antenna 1 and 2 at 3.13 GHz.

The designed antenna simulation results so far presented are general operational characteristics for any radiating structure and the parameters that are of high interest, specific to the MIMO antenna, are as follows. The major parameters that determine the MIMO antennas' performance are the Envelope Correlation Coefficient (ECC) and Diversity Gain (DG). The secondary parameters that are of major interest are the Mean effective gain and TARC values of the MIMO Antenna. The analysis of the specific parameters for both antennas is presented.

The resultant ECC values obtained from Antenna 1 to 2 ranges from 0.000043 to 0.005, and these ECC values showcased are exceptionally low, as the ECC values are expected to be within 0.5, thus the presented antenna 1 ECC value indicates that there is very good isolation and minimal mutual coupling between the 1×2 MIMO elements. Similarly, the ECC values obtained for the Antenna 2 to 1 ranges from 0.00034 to 0.008 is extremely less, and the values indicate that there is a very good isolation and weak correlation.

These ECC Values indicate that the designed 1×2 antenna is highly suitable for the application in advanced MIMO systems like 5G networks, Vehicular communication and IOT networks where spatial diversity and low correlation factors are key.

The designed asymmetric CPW-fed antenna holds great promise for the application in advanced communication systems with the efficient Mean Effective Gain (MEGi) value of 0.365 and 0.260 TARC value. The achieved antenna Isolation (S_{21}) in (dB) is around -43.325. Its multiband operation, compact form factor, and MIMO capabilities position it as a valuable component in the ever-evolving landscape of wireless communication technologies. The findings from this research, shown in Tables 1 and 2, contribute to the ongoing efforts to realize the full potential of advanced communication standards and pave the way for future innovations in wireless connectivity. From the comparison Table 3, it can be observed that the designed trapezoidal MIMO Antenna has consistent performance metrics such as ECC, DG, TARC, and MEGi, along with the improved radiation efficiency and Gain supporting five different advanced wireless communication applications. Although the antenna size is relatively large, it can be reduced in the future to ensure compactness. Even though the proposed trapezoidal asymmetric CPW-fed 1×2 MIMO antenna displays promising performance characteristics through simulation, signifying necessary metrics such as low ECC, high DG, suitable TARC and MEGi, and sturdy radiation efficiency, the experimental validation remains an important step for practical deployment. Owing to current resource and facility limitations, physical fabrication and measurement of the presented 1×2 MIMO prototype could not be completed.

Table 1. Summary of simulation results of antenna 1.

Band (GHz)	BW in (MHz)	Far-Field Peak Gain (dBi)	RL	ECC	Diversity Gain
3.01 – 3.46	450	5.51	-13.29	0.005	9.99
6.74 – 7.19	450	6.97	-22.21	0.0001	9.98
10.56 – 11.14	580	5.75	-24.42	0.000045	9.99
14.17 – 14.60	430	6.76	-11.62	0.000043	9.99
17.63 – 18.05	420	6.45	-11.31	0.000089	9.99

Table 2. Summary of simulation results of antenna 2.

Band (GHz)	BW in (MHz)	Far-Field Peak Gain (dBi)	RL	ECC	Diversity Gain
3.05 – 3.52	450	5.21	-14.92	0.0006	9.99
6.74 – 7.19	450	6.7	-22.37	0.0008	9.98
10.57 – 11.14	580	6.08	-24.47	0.00050	9.99
14.17 – 14.60	430	6.48	-11.69	0.00034	9.98
17.65 – 18.05	420	6.39	-11.26	0.00063	9.99

Table 3. Performance assessment with existing MIMO antennas.

Ref. No	Size (mm ²)	Freq. Band	ECC	DG (dB)	Gain (dBi)
[17]	40 x 20	38.35 - 38.66	0.00014	9.994	6.84
[18]	82 x 82	Dual-band	0.005	9.81	6
[19]	16 x 28	Triple Band	0.04	9.5	3.49, 2.24, 3.41
[20]	38.6 x 38.6	Dual-band	0.007	9.8	7, 6.5
[21]	120 x 40	Single Band	Not Specified	Not Specified	7.38
[22]	92.73 x 28.62	Single Band	Not Specified	Not Specified	9.3
[23]	55.27 x 27.635	27–40 GHz	0.002	9.96	5.5
[24]	41 x 41	2.4 and 5.9 GHz	0.002	9.98 to 10	4.5
[25]	120 x 100	2.56 – 4.35 GHz	0.01	Not Specified	2.36
[26]	93 x 93	Sub-6 GHz Band	0.003	9.89	5.54
Proposed MIMO Antenna	320 x 160	Penta-Band	0.00034-0.0008	9.98	6.5

5. Conclusion

In conclusion, the development of an asymmetric CPW-fed 1×2 MIMO antenna tailored for advanced wireless communication applications like 5G, X-band Radar, and Fixed Satellite Services has been successfully designed and realized. The antenna demonstrates several pivotal characteristics that render it appropriate for next-generation wireless communication infrastructures. First of all, highlight that the designed antenna has its Multi-band operating capability covering the 1–20 GHz frequency range. Secondly, its consistent and high-gain operating characteristics in the range of 5 dBi and efficient radiation efficiency of 98% make it a suitable candidate for modern high-speed wireless systems. Next, is that the

stable and directional radiation pattern along with the very low ECC values, high DG indicates the high suitability of the designed antenna for MIMO applications. Through comprehensive simulation and theoretical calculations, the performance of the designed trapezoidal asymmetric CPW-fed 1×2 MIMO antenna has been rigorously validated, substantiating its ability to fulfil the rigorous specifications associated with modern wireless communication applications. To further enhance the antenna performance, metamaterial loading can be performed in the future.

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