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Design and Analysis of Sub-6 GHz Dual-Band MIMO Dielectric Resonator Antenna for 5G Communication

Dr. K.M. Palaniswamy (Professor), Baavanesh S, Rithik B, Suresh P
Department of ECE, Dr. T. Thimmaiah Institute of Technology, KGF, Karnataka, India

Abstract: The MIMO Dielectric Resonator Antenna is tailored for Sub-6 GHz 5G communication, featuring F-shaped patches with four dielectric materials over a ground plane. It operates in dual-band resonance with impressive port isolation exceeding 20 dB, eliminating the need for extra isolation mechanisms. Aperture feeding enhances efficiency, while alumina DR minimizes signal losses. Mounted on an FR-4 substrate with copper patches, the antenna undergoes design phases for optimal performance in Sub-6 5G bands, aiming for effective communication within the specified frequency range.

Keywords: Sub 6GHz, MIMO, Dielectric Resonator, Dual Band, 5G Communication, Alumina Dielectric.

I INTRODUCTION

The increasing demand for real-time internet usage requires faster and more efficient communication than what 3G and 4G networks can provide. 5G has emerged as a solution, supporting data rates in the gigabits per second range and offering lower latency compared to 4G. One key technology driving this evolution is Multiple-Input Multiple-Output (MIMO), which enhances channel capacity, reduces multipath fading, and enables faster communication. MIMO optimizes spectrum efficiency, allowing for more simultaneous users through better channel allocation. This advancement signifies a significant leap forward in communication technology, catering to the growing needs of modern data streaming. In 5G communication, an array of antennas is employed to combat radio propagation challenges. MIMO technology addresses these issues by leveraging multiple transmit and receive antennas, which helps mitigate fading inconsistencies. Various multiplexing techniques provide flexibility in MIMO communication. However, due to space constraints in 5G mobile communication, compact antenna solutions are required. Planar resonators emerge as a practical choice for accommodating multiple antennas within limited physical space. 5G communication uses arrays of antennas to tackle radio propagation hurdles. MIMO technology utilizes multiple transmit and receive antennas to counter fading discrepancies. Different multiplexing methods offer versatility in MIMO communication. Yet, space limitations in 5G mobile setups demand compact antenna designs. Planar resonators prove to be a viable option for fitting multiple antennas into constrained spaces effectively. The deployment of 5G technology encompasses a spectrum of frequencies, each tailored to specific needs within the wireless landscape. In the low-band spectrum, frequencies below 1 GHz ensure expansive coverage and reliable connectivity, particularly advantageous for rural areas. Progressing to the mid-band spectrum, spanning 1 GHz to 6 GHz, 5G strikes a balance between speed and accessibility, serving urban and suburban environments with faster data rates and reasonable coverage. At the high-band spectrum, including millimeter-wave frequencies above 24 GHz, 5G delivers unparalleled data speeds, albeit with limited coverage and susceptibility to obstacles. This spectrum diversity facilitates a versatile and efficient wireless ecosystem, catering to a multitude of use cases and accommodating the varying demands of modern connectivity requirements. In the realm of 5G technology, the sub-6 GHz spectrum acts as the foundational engine, providing widespread coverage and reliable connectivity across various environments. Its frequencies below 6 GHz excel in traversing

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obstacles and ensuring fast internet access, making it indispensable for seamless 5G experiences in both urban and remote locations. On the other hand, 5G mmWave frequencies, operating beyond 24 gigahertz, offer unparalleled speed and low-latency communication capabilities. Despite challenges such as limited coverage and obstacle interference due to their shorter wavelengths, mmWave technology empowers lightning-fast data transfers and supports cutting-edge applications like virtual reality. Leveraging advanced techniques such as beamforming and specialized antennas, 5G mmWave deployment focuses primarily on urban areas, driving innovation and shaping the future landscape of wireless networks. A dielectric resonator, typically made from ceramic materials, acts as a key element in microwave devices like antennas and filters. It stores and releases electromagnetic energy at specific frequencies, aiding in efficient communication, especially at high frequencies. Engineers leverage its size and shape to tune it for optimal performance in various electronic systems operating within microwave and millimeter-wave ranges, ensuring reliable and effective wireless communication across different applications. FR-4, a commonly used material in antenna construction, boasts favorable dielectric properties that enable effective control of electromagnetic waves. Its high dielectric constant is particularly advantageous for manipulating these waves within the antenna structure. Moreover, FR-4 exhibits low signal loss, ensuring efficient transmission and reception of signals. Combining mechanical strength derived from its fiberglass component with stability across temperatures, FR-4 offers reliability in diverse environmental conditions. Its ease of fabrication further enhances its appeal, making it a versatile and cost-effective option for constructing antennas for various applications, notably in wireless communication systems. Alumina, also referred to as aluminum oxide, is indispensable as a dielectric material in antenna design due to its array of advantageous properties. Its high dielectric constant facilitates precise regulation of electromagnetic wave propagation within antennas, ensuring efficient signal transmission. Alumina's low loss tangent minimizes energy dissipation, enhancing overall communication effectiveness. Renowned for its high-temperature stability and mechanical robustness, alumina guarantees antenna durability even in demanding conditions, while its chemical resistance adds an extra layer of reliability. Alumina's versatility shines through in enabling antenna miniaturization, a crucial feature for compact designs in modern electronic devices where space constraints are common. Moreover, its dielectric properties can be tailored for specific frequency bands, allowing for optimized antenna performance across diverse applications. A Dielectric Resonator Antenna (DRA) capitalizes on a dielectric resonator as its primary radiating element, typically composed of a high-permittivity material designed to resonate at a specific frequency upon stimulation by an electromagnetic wave. Within the realm of wireless communication, the 6 GHz frequency band emerges as pivotal, offering a spectrum range fundamental for diverse applications necessitating high-speed data transmission and connectivity. In antenna engineering, the concept of dual-band resonance signifies the antenna's adeptness at operating effectively across two distinct frequency bands. This capability enhances the antenna's versatility, enabling seamless support for communication or transmission needs across multiple frequencies, thus catering to various wireless communication requirements. MIMO antennas are pivotal in achieving low mutual coupling between ports, ensuring high isolation or low correlation to enhance radiation and diversity performance, particularly in space-constrained environments where electrical compactness is crucial. Various strategies, including decoupling mechanisms and resonator placement, are employed to achieve port isolation. Internal mode decoupling, often utilized, ensures opposite current flow directions in resonators to mitigate correlation between elements. The WiMAX communication standard, renowned for its broadband services and longer-distance coverage compared to WiFi benefits from MIMO technology's multiple resonant frequencies. Recent literature showcases state-of-the-art MIMO antennas, with research emphasizing effective utilization of the 3–300 GHz spectrum to balance user coverage and channel capacity, akin to 3G and 4G communication standards. Engineering dielectric resonators allows for improved

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antenna parameters such as directivity, gain, bandwidth, and cross-polarization isolation. The presented design innovatively leverages dielectric resonator manipulation to excite dual-band operation with TE01δ and TE10δ modes, ensuring electrical compactness and finding excellent applications in Sub-6 GHz and WiMAX communication scenarios.

II. PROPOSED ANTENNA DESIGN

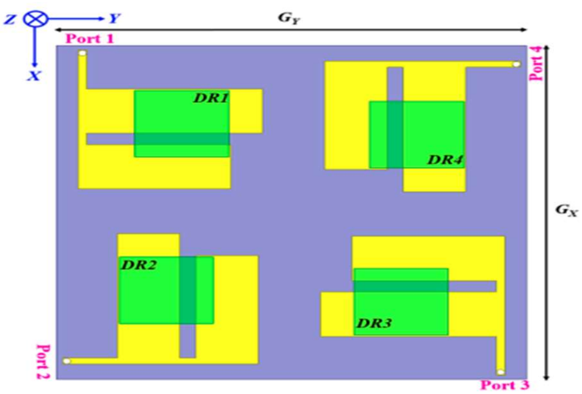

Fig 1: Top view of Four Port Dielectric Resonator Antenna

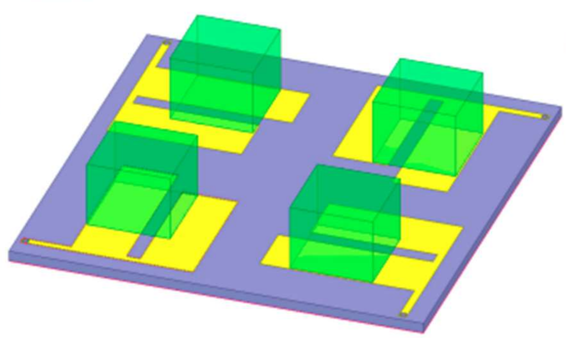

Fig 2: Side view of Four Port Dielectric Resonator *Antenna*

The proposed MIMO antenna design comprises four resonating elements, incorporating both dielectric and patch resonators. Achieving optimal diversity performance necessitates maintaining low correlation between antenna ports and minimizing mutual coupling among the four elements. To meet these requirements, adjustments were made to the substrate dimensions while ensuring overall electrical proportions were maintained. Atop the substrate, four identical modified inverted F-shaped radiators are positioned orthogonally, with four distinct alumina dielectric resonators (DR1, DR2, DR3, and DR4) integrated over them. The full ground profile of the resonator is retained at the back. Extensive iterative simulations were conducted to achieve electrical compactness without significant compromises in port isolation. The ground plane and substrate dimensions were retained at 60 mm, while the overall resonator dimensions are 60 × 60 × 11.6 mm^3. Dielectric resonators are connected to the patch resonator using conducting adhesive.

The escalating demand for high-speed internet, driven by the limitations of 3G and 4G communications, has catalyzed the development of more efficient technologies such as 5G. Offering gigabit-per-second data rates, reduced latency, and improved channel capacity, 5G heavily relies on multiple-input multiple-output (MIMO) technology to tackle signal fading and optimize spectrum utilization. In this context, advanced antennas are indispensable, and dielectric resonator antennas (DRAs) have emerged as a promising solution due to their efficient radiation capabilities. Utilizing engineered dielectric resonators, DRAs offer advantages such as compact size, high radiation efficiency, and versatility in design, making them well-suited for the diverse frequency requirements of emerging 5G applications.

Design Of Antenna in CST Studio Suite 2021

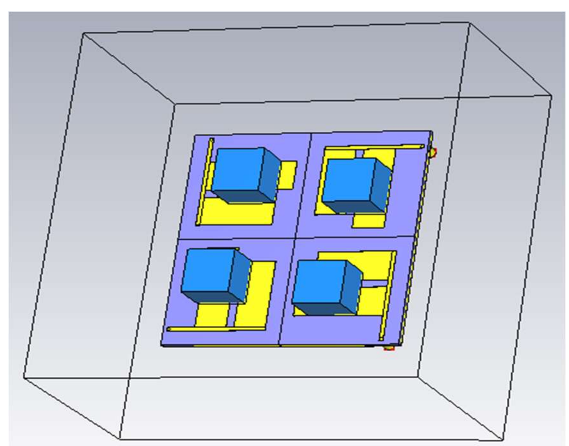

Fig 3: Four Port Dielectric Resonator Antenna

A Four Port Dielectric Resonator Antenna (DRA) is designed to facilitate multiple-input multiple-output

(MIMO) communication systems, crucial for enhancing data rates and reliability in modern wireless networks. The antenna configuration incorporates four resonating elements, comprising both dielectric and patch resonators, strategically positioned to ensure low correlation between antenna ports and minimal mutual coupling among the elements. Achieving optimal diversity performance necessitates careful adjustments to substrate dimensions while maintaining overall electrical proportions. Atop the substrate, four identical modified inverted F-shaped radiators are positioned orthogonally, each hosting a distinct alumina dielectric resonator (DR1, DR2, DR3, and DR4). Extensive iterative simulations are conducted to optimize electrical compactness while preserving port isolation. The ground plane and substrate dimensions are retained at predetermined values to ensure consistent performance. Dielectric resonators are effectively integrated with the patch resonator using conducting adhesive, ensuring reliable connectivity. Overall, the Four Port Dielectric Resonator Antenna represents an advanced solution tailored for MIMO systems, offering improved data rates and robust communication capabilities in various wireless applications.

III. ANTENNA DESIGN AND SIMULATIONS

The conducting patch of the antenna transfers electromagnetic fields to a dielectric resonator (DR), exciting it and enabling signal transmission. To ensure efficient power transfer, an offset feeding technique is utilized for impedance matching. The dimensions of the microstrip feedline are initially computed and then optimized to effectively feed the patch antenna. The antenna is constructed on a standard low-cost FR-4 substrate with specific dielectric properties. Copper sheets with a thickness of 35 µm are employed for the patch design. Unlike some DR-based MIMO antennas with taller configurations for improved parameters, the chosen square DR's dimensions are constrained by space limitations. The decision to use a square DR over a circular or cylindrical one is primarily based on mechanical feasibility and ease of placement optimization. Square DRs simplify the antenna design process and enable better prediction of antenna behavior during optimization. Although accurately modeling the combined patch and dielectric material behavior is challenging, software simulations aid in achieving target parameters. Equations describing DRA excitation modes assist in estimating antenna resonance, while avoiding issues with degenerated modes commonly associated with circular or cylindrical DRs.

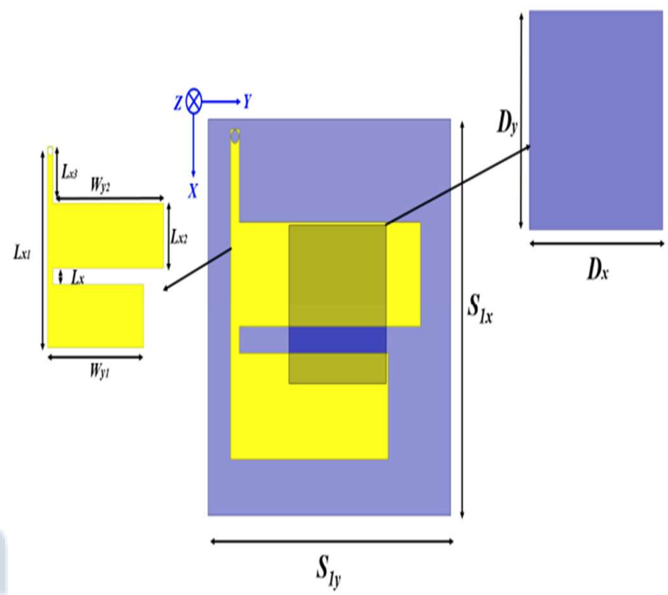

Fig 4: Geometry of the Antenna

Dimensions Of the DRA

The dimensions of the resonator are pivotal in shaping the antenna's resonance and radiation characteristics. Adjustments to the electrical dimensions of the resonators can excite different resonant modes, profoundly impacting antenna performance. Various techniques have been explored to enhance antenna radiation parameters by modifying these dimensions. Through extensive simulation iterations, physical adjustments were made to the antenna's dimensions to achieve desired parameters. Altering the length and width of the dielectric resonator significantly influenced resonant frequencies by affecting the electrical current path of the antenna. Similarly, changes in resonator height and the gap between flares caused shifts in resonance frequency. The length variations of the upper and lower flares also altered the antenna's effective electrical length, affecting resonance. However, achieving desired parameters

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required balancing trade-offs, as changes in one dimension could impact impedance matching and resonance frequencies differently for each band. Minor variations in reflection coefficient and resonance frequencies were observed with changes in flare width, while modifications to the location of the offset feed led to significant changes in impedance matching at the target resonance, ultimately affecting antenna performance. Consideration of environmental factors and novel tuning mechanisms may enhance real-world adaptability. Exploration of multi-resonator interactions could lead to wideband antenna designs. Practical validation through experimentation is crucial for confirming simulation results.

Parameters	Values (mm)
$S_{1x} = S_{2x}$	30
$D_x = D_y$	12
L_x	2
L_{x1}	25
L_{x2}	8
L_{x3}	7
W_{y1}	19.5
W_{y2}	22.4
Dh	10
t	1.6

Table 1: Geometrical Dimensions of DRA

IV. SIMULATED RESULTS

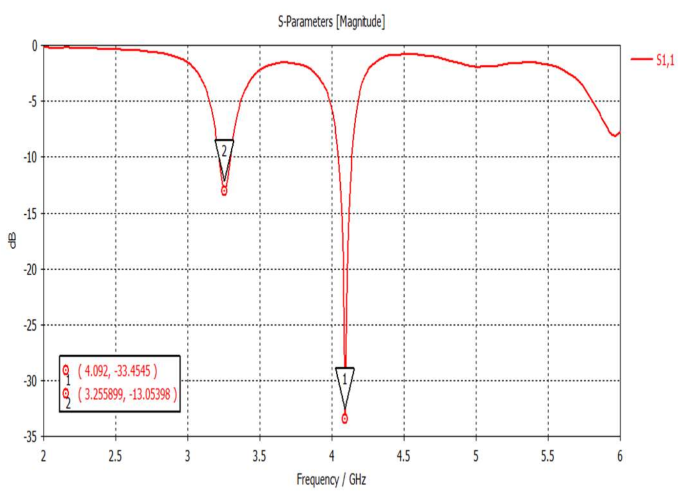

Fig 5: Simulated S parameter of MIMO DRA

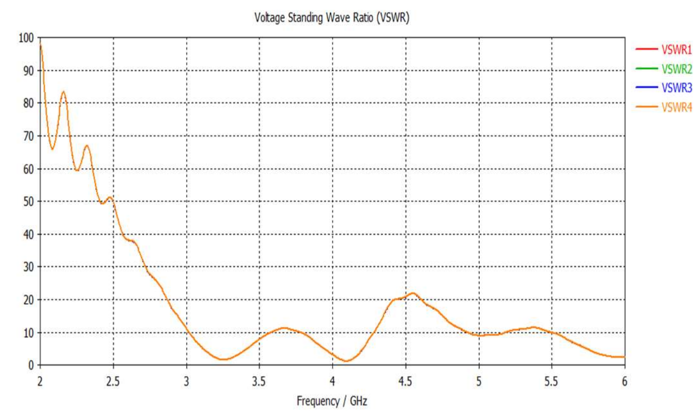

Fig 6: Simulated VSWR of MIMO DRA

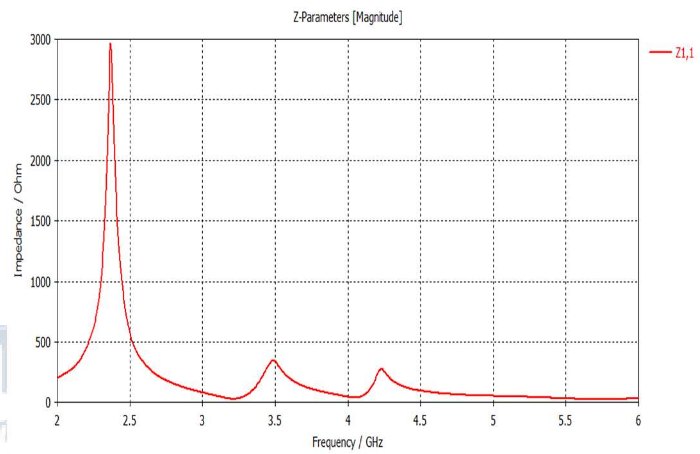

Fig 7: Simulated Z Parameter of MIMO DRA

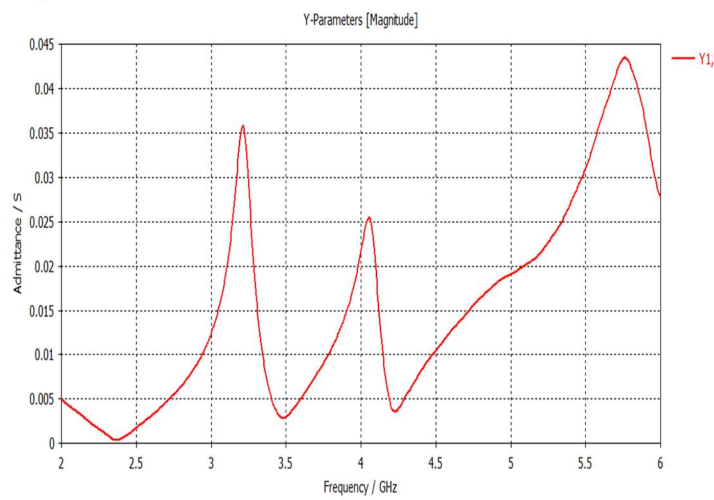

Fig 8: Simulated Y Parameter of MIMO DRA

V. CONCLUSION

In conclusion, the project on the "Design and Analysis of a Dielectric Resonator Antenna for 5G Communication Applications" concludes with the successful realization of the Dielectric Resonator Antenna (DRA). This journey involved installing CST software, conducting precise design calculations, and constructing a fundamental antenna, offering a comprehensive understanding of the entire process. The results obtained not only offer valuable insights into the antenna's performance but also demonstrate proficiency in utilizing CST software for advanced design considerations. This achievement signifies the successful completion of the project, laying a solid groundwork in fundamental concepts and positioning it for future endeavors. It represents a significant contribution to the dynamic field of 5G communication technology. Specifically, a four-port dielectric resonator (DR)-based multiple-input multiple-output (MIMO) antenna was designed for sub-6 GHz communication, achieving dual-band resonance through aperture feeding. Simulation results indicate favorable MIMO diversity parameters, with orthogonal alignment of DRA elements enabling polarization and spatial diversity, rendering it suitable for sub-6 GHz 5G and WiMAX applications.

REFERENCES

[1] Sharawi, M.S. Printed multi-band MIMO antenna systems and their performance metrics [wireless corner]. IEEE Antennas Propag. Mag. 2013, 55, 218–232. [CrossRef]

[2] Karaboikis, M.P.; Papamichael, V.C.; Tsachtsiris, G.F.; Soras, C.F.; Makios, V.T. Integrating compact printed antennas onto small diversity/MIMO terminals. IEEE Trans. Antennas Propag. 2008, 56, 2067–2078. [CrossRef]

[3] Huang, H.; Li, X.; Liu, Y. A low-profile, dual-polarized patch antenna for 5G MIMO application. IEEE Trans. Antennas Propag. 2018, 67, 1275–1279. [CrossRef]

[4] Li, Y.; Zhao, Z.; Tang, Z.; Yin, Y. Differentially fed, dual-band dual-polarized filtering antenna with high selectivity for 5G sub-6 GHz base station applications. IEEE Trans. Antennas Propag. 2019, 68, 3231–3236. [CrossRef]

[5] Le Thi, C.H.; Ta, S.X.; Nguyen, X.Q.; Nguyen, K.K.; Dao-Ngoc, C. Design of compact broadband dual-polarized antenna for 5G applications. Int. J. RF Microw. Comput. Aided Eng. 2021, 31, e22615. [CrossRef]

[6] Chouhan, S.; Panda, D.K.; Kushwah, V.S.; Mishra, P.K. Octagonal-shaped wideband MIMO antenna for human interface device and S-band application. Int. J. Microw. Wirel. Technol. 2019, 11, 287–296. [CrossRef]

[7] Yadav, S.K.; Kaur, A.; Khanna, R. Compact Rack Shaped MIMO Dielectric Resonator Antenna with Improved Axial Ratio for UWB Applications. Wirel. Pers. Commun. 2021, 117, 591–606. [CrossRef]

[8] Girjashankar, P.R.; Upadhyaya, T. Substrate integrated waveguide fed dual band quad-elements rectangular dielectric resonator MIMO antenna for millimeter wave 5G wireless communication systems. AEU-Int. J. Electron. Commun. 2021, 137, 153821. [CrossRef]

[9] Anuar, S.U.; Jamaluddin, M.H.; Din, J.; Kamardin, K.; Dahri, M.H.; Idris, I.H. Triple band MIMO dielectric resonator antenna for LTE applications. AEU-Int. J. Electron. Commun. 2020, 118, 153172. [CrossRef]

[10] Dwivedi, A.K.; Sharma, A.; Singh, A.K.; Singh, V. Circularly polarized quad-port MIMO dielectric resonator antenna with beam tilting feature for vehicular communication. IETE Tech. Rev. 2020, 39, 389–401. [CrossRef]

[11] Alibakhshikenari, M.; Babaeian, F.; Virdee, B.S.; Aïssa, S.; Azpilicueta, L.; See, C.H.; Althuwayb, A.A.; Huynen, I.; Abd-Alhameed, R.A.; Falcone, F.; et al. A comprehensive survey on "Various decoupling mechanisms with focus on metamaterial and metasurface principles applicable to SAR and MIMO antenna systems". IEEE Access 2020, 8, 192965–193004. [CrossRef]

[12] Wang, Z.; Li, C.; Wu, Q.; Yin, Y. A metasurface-based low-profile array decoupling technology to enhance isolation in MIMO antenna systems. IEEE Access 2020, 8, 125565–125575. [CrossRef]

[13] Bhattacharjee, A.; Karmakar, A.; Saha, A.; Bhattacharya, D. Design of a compact UWB MIMO-diversity antenna incorporating fractal inspired isolation structure with band notch characteristics. Microw. Opt. Technol. Lett. 2021, 63, 2597–2605. [CrossRef]

[14] Yang, Z.; Xiao, J.; Ye, Q. Enhancing MIMO antenna isolation characteristic by manipulating the propagation of surface wave. IEEE Access 2020, 8, 115572–115581. [CrossRef]

[15]Tang, J.; Faraz, F.; Chen, X.; Zhang, Q.; Li, Q.; Li, Y.; Zhang, S. A metasurface superstrate for mutual coupling reduction of large antenna arrays. IEEE Access 2020, 8, 126859–126867. [CrossRef]

[16] Deng, J.Y.; Li, J.Y.; Guo, L.X. Decoupling of a three-port MIMO antenna with different impedances using reactively loaded dummy elements. IEEE Antennas Wirel. Propag. Lett. 2018, 17, 430–433. [CrossRef]

[17] Roy, S.; Chakraborty, U. Mutual coupling reduction in a multi-band MIMO antenna using meta-inspired decoupling network. Wirel. Pers. Commun. 2020, 114, 3231–3246. [CrossRef]

[18] Moussa, K.H.; Amar, A.S.; Mabrouk, M.; Mohamed, H.G. Slotted E-Shaped Meta-Material Decoupling Slab for Densely Packed MIMO Antenna Arrays. Micromachines 2021, 12, 873. [CrossRef]

[19] Li, M.; Cheung, S. A novel calculation-based parasitic decoupling technique for increasing isolation in multiple-element MIMO antenna arrays. IEEE Trans. Veh. Technol. 2020, 70, 446–458. [CrossRef]

[20] Ding, C.F.; Zhang, X.Y.; Xue, C.D. Novel pattern-diversity-based decoupling method and its application to multielement MIMO antenna. IEEE Trans. Antennas Propag. 2018, 66, 4976–4985. [CrossRef]

[21]Kumar, S.; Nandan, D.; Srivastava, K.; Kumar, S.; Singh, H.; Marey, M.; Mostafa, H.; Kanaujia, B.K. Wideband circularly polarized textile MIMO antenna for wearable applications. IEEE Access 2021, 9, 108601–108613. [CrossRef]

[22] Huang, J.; Dong, G.; Cai, J.; Li, H.; Liu, G. A quad-port dual-band MIMO antenna array for 5G smartphone applications. Electronics 2021, 10, 542. [CrossRef]

[23] Pant, A.; Singh, M.; Parihar, M.S. A frequency reconfigurable/switchable MIMO antenna for LTE and early 5G applications. AEU-Int. J. Electron. Commun. 2021, 131, 153638. [CrossRef]

[24] El Hadri, D.; Zakriti, A.; Zugari, A.; El Ouahabi, M.; El Aoufi, J. High isolation and ideal correlation using spatial diversity in a compact MIMO antenna for fifth-generation applications. Int. J. Antennas Propag. 2020, 2020, 2740920. [CrossRef]

[25] Jin, X.; Qiu, Y.; Wu, D.; Yu, G.; Guo, R.; Wu, G.; Zhu, M.; Zhou, H.M. A Low-Profile Dual-Polarized MIMO Antenna with an AMC Surface for WLAN Applications. Int. J. Antennas Propag. 2021, 2021, 9218255. [CrossRef]

[26] Laxman, P.; Jain, A. Circularly Polarized Wideband Fabric Stealth Multiple-Input Multiple-Output Antenna for Ultrawideband Applications Useful for

Wireless Systems Wearable on Garments. Int. J. Antennas Propag. 2021, 2021, 1426680. [CrossRef]

[27]Daghari, M.; Essid, C.; Sakli, H. Muli-UWB Antenna System Design for 5G Wireless Applications with Diversity. Wirel. Commun. Mob. Comput. 2021, 2021, 9966581. [CrossRef]

[28] Upadhyaya, T.; Park, I.; Pandey, R.; Patel, U.; Pandya, K.; Desai, A.; Pabari, J.; Byun, G.; Kosta, Y. Aperture-Fed Quad-Port Dual-Band Dielectric Resonator-MIMO Antenna for Sub-6 GHz 5G and WLAN Application. Int. J. Antennas Propag. 2022, 2022, 4136347. [CrossRef]

[29] Ali, A.; Tong, J.; Iqbal, J.; Illahi, U.; Rauf, A.; Rehman, S.U.; Ali, H.; Qadir, M.M.; Khan, M.A.; Ghoniem, R.M. Mutual Coupling Reduction through Defected Ground Structure in Circularly Polarized, Dielectric Resonator-Based MIMO Antennas for Sub-6 GHz 5G Applications. Micromachines 2022, 13, 1082. [CrossRef]

[30] Singhwal, S.S.; Kanaujia, B.K.; Singh, A.; Kishor, J.; Matekovits, L. Multiple input multiple output resonator antenna with circular polarized adaptability for 5G applications. J. Electromagn. Waves Appl. 2020, 34, 1180–1194. [CrossRef]

[31] 31. Iqbal, A.; Nasir, J.; Qureshi, M.B.; Khan, A.A.; Rehman, J.U.; Rahman, H.U.; Fayyaz, M.A.; Nawaz, R. A CPW fed quad-port MIMO DRA for sub-6 GHz 5G applications. PLoS ONE 2022, 17, e0268867. [CrossRef] [PubMed]

[32] Roshani, S.; Yahya, S.I.; Alameri, B.M.; Mezaal, Y.S.; Liu, L.W.; Roshani, S. Filtering Power Divider Design Using Resonant L Branches for 5G Low-Band Applications. Sustainability 2022, 14, 12291. [CrossRef]

[33]Sarkar, G.A.; Ballav, S.; Chatterjee, A.; Ranjit, S.; Parui, S.K. Four element MIMO DRA with high isolation for WLAN applications. Prog. Electromagn. Res. Lett. 2019, 84, 99–106. [CrossRef]

[34]Dwivedi, A.K.; Sharma, A.; Singh, A.K.; Singh, V. Design of dual band four port circularly polarized MIMO DRA for WLAN/WiMAX applications. J. Electromagn. Waves Appl. 2020, 34, 1990–2009. [CrossRef]

[35] Varshney, G.; Singh, R.; Pandey, V.S.; Yaduvanshi, R.S. Circularly polarized two-port MIMO dielectric resonator antenna. Prog. Electromagn. Res. M 2020, 91, 19–28. [CrossRef]

[36]Fakhte, S.; Oraizi, H. Compact uniaxial anisotropic dielectric resonator antenna operating at higher order radiating mode. Electron. Lett. 2016, 52, 1579–1580. [CrossRef]

[37]Mukherjee, B.; Patel, P.; Mukherjee, J. Hemispherical dielectric resonator antenna based on apollonian gasket of circles—A fractal approach. IEEE Trans. Antennas Propag. 2013, 62, 40–47. [CrossRef]

[38]Sharma, A.; Biswas, A. Wideband multiple-input–multiple-output dielectric resonator antenna. IET Microw. Antennas Propag. 2017, 11, 496–502. [CrossRef]

[39] Maity, S.; Gupta, B. Experimental investigations on wideband triangular dielectric resonator antenna. IEEE Trans. Antennas Propag. 2016, 64, 5483–5486. [CrossRef]