

## References

- [1] C. A. Balanis, “Antenna theory analysis and design,” Fourth Edition, *John Wiley and Sons, Inc.*, 2016.
- [2] J. G. Proakis, “Digital communications,” Fourth Edition, *McGraw-Hill*, New York, 2001.
- [3] J. H. Winters, “Optimum combining in digital mobile radio with co-channel interference,” *IEEE Transactions on Vehicular Technology*, vol. VT-33, no. 3, pp. 144–155, 1984.
- [4] A. J. Paulraj and T. Kailath, “Increasing capacity in wireless broadcast systems using distributed transmission/directional reception (DTDR),” *US Patent*, no. 5345599, 1994.
- [5] G. J. Foschini, “Layered space-time architecture for wireless communication in fading environment when using multi element antennas,” *Bell Lab Technical Journal*, vol. 1, no. 2, pp. 41–59, 1996.
- [6] G. G. Raleigh and J. M. Cioffi, “Spatio-temporal coding for wireless communication,” *IEEE Transaction on Antennas Propagation*, vol. 46, no. 3, pp. 357–366, 1998.
- [7] G. G. Raleigh and V. K. Jones, “Multivariate modulation and coding for wireless applications,” *IEEE Journal on Selected Areas in Communication*, vol. 17, no. 5, pp. 851–866, 1999.
- [8] G. D. Golden, C. J. Foschini, R. A. Valenzuela, and P. W. Wolniansky, “Detection algorithm and initial laboratory results using V-BLAST space-time communication architecture,” *Electronics Letters*, vol. 35, no. 1, pp. 14–16, 1999.
- [9] J. H. Winters, “On the capacity of radio communication system with diversity in a Rayleigh fading environment,” *IEEE Journal on Selected Area in Communication*, vol. SAC-5, no. 5, pp. 871–878, 1987.
- [10] G. J. Foschini and M. J. Gans, “On limits of wireless communication in a fading environment when using multiple antennas,” *Wireless Personal Communication*, vol. 6, no. 3, pp. 311–335, 1998.
- [11] D. S. Shiu, G. J. Foschini, M. J. Gans, and J. M. Kahn, “Fading correlation and its effects on the capacity of multi-element antenna system,” *IEEE Transaction on Communications*, vol. 48, no. 3, pp. 502–513, 2000.
- [12] D. Gesbert and J. Akhtar, “Breaking the barriers of Shannon’s capacity: an overview of MIMO wireless systems,” *Signal Process.*, vol. 1, no. B2, p. B3, 2002.
- [13] X. Chen, S. Zhang, and Q. Li, “A review of mutual coupling in MIMO systems,” *IEEE Access*, vol. 6, pp. 24706–24719, 2018.

- 
- [14] I. Nadeem and D. Choi, "Study on mutual coupling reduction technique for MIMO antennas," *IEEE Access*, vol. 7, pp. 563–586, 2019.
- [15] M. Manteghi and Y. R. Samii, "Broadband characterization of the total active reflection coefficient of multiport antennas," *Proceedings IEEE Antennas and Propagation Society International Symposium*, Ohio, USA, pp. 20–23, 2003.
- [16] W. L. Stutzman and G. A. Thiele, "Antenna theory and design," *John Wiley & Sons*, 1981.
- [17] C. Gandy, "Dipole antennas," *BCC Research & Development*, White Paper WHP 132, 2006.
- [18] B. Allen, M. Dohler, E. E. Okon, W. Q. Malik, A. K. Brown, and D. J. Edwards, "Ultra-wideband antennas and propagation for communications, radar and imaging," *John Wiley & Sons Ltd.*, 2007.
- [19] G. Kumar and K. P. Ray, "Broadband microstrip antennas," *MA: Artech House*, Boston, 2003.
- [20] K. G. Thomas and M. Sreenivasan, "A simple ultrawideband planar rectangular printed antenna with band dispensation," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 1, pp. 27–34, 2010.
- [21] C.-X. Mao and Q.-X. Chu, "Compact coradiator UWB-MIMO antenna with dual polarization," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 9, pp. 4474–4480, 2014.
- [22] S. Soltani and R. D. Murch, "A compact planar printed MIMO antenna design," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 3, pp. 1140–1149, 2015.
- [23] M. P. Karaboikis, V. C. Papamichael, G. F. Tsachtsiris, C. F. Soras, and V. T. Makios, "Integrating compact printed antennas onto small diversity/MIMO terminals," *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 7, pp. 2067–2078, 2008.
- [24] S. Zhang, B. K. Lau, A. Sunesson, and S. He, "Closely-packed UWB MIMO/diversity antenna with different patterns and polarizations for USB dongle applications," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 9, pp. 4372–4380, 2012.
- [25] R. Tian, B. K. Lau, and Z. Ying, "Multiplexing efficiency of MIMO antennas," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 183–186, 2011.
- [26] J. Thaysen and K. B. Jakobsen, "Envelope correlation in (N, N) MIMO antenna array from scattering parameters," *Microwave and Optical Technology Letters*, vol. 48, no. 5, pp. 832–834, 2006.
- [27] M. S. Sharawi, "Printed multi-band MIMO antenna systems and their performance metrics," *IEEE Antennas and Propagation Magazine*, vol. 55, no. 5, pp. 218–232, 2013.

- [28] R. Hussain, M. S. Sharawi, and A. Shamim, "4-Element concentric pentagonal slot-line-based ultra-wide tuning frequency reconfigurable MIMO antenna system," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 8, pp. 4282–4287, 2018.
- [29] S. H. Chae, S.-K. Oh, and S.-O. Park, "Analysis of mutual coupling, correlations, and TARC in WiBro MIMO array antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 6, pp. 122–125, 2007.
- [30] C. H. See, R. A. Abd-Alhameed, Z. Z. Abidin, N. J. McEwan, and P. S. Excell, "Wideband printed MIMO/diversity monopole antenna for WiFi/WiMAX applications," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 4, pp. 2028–2035, 2012.
- [31] R. G. Vaughan and J. B. Andersen, "Antenna diversity in mobile communications," *IEEE Transactions on Vehicular Technology*, vol. VT-36, no. 4, pp. 149–172, 1987.
- [32] C. B. Dietrich, K. Dietze, J. R. Nealy, and W. L. Stutzman, "Spatial, polarization, and pattern diversity for wireless handheld terminals," *IEEE Transactions on Antennas and Propagation*, vol. 49, no. 9, pp. 1271–1281, 2001.
- [33] M. Niroo-Jazi, T. A. Denidni, M. R. Chaharmir, and A. R. Sebak, "A hybrid isolator to reduce electromagnetic interactions between Tx/Rx antennas," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 75–78, 2014.
- [34] Z. Yang, J. Xiao, and Q. Ye, "Enhancing MIMO antenna isolation characteristic by manipulating the propagation of surface wave," *IEEE Access*, vol. 8, pp. 115572–115581, 2020.
- [35] M. Li, M. Y. Jamal, L. Jiang, and K. L. Yeung, "Isolation enhancement for MIMO patch antennas sharing a common thick substrate: using a dielectric block to control space-wave coupling to cancel surface-wave coupling," *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 4, pp. 1853–1863, 2021.
- [36] S. S. Attwood, "Surface-wave propagation over a coated plane conductor," *Journal of Applied Physics*, vol. 22, no. 4, pp. 504–509, 1951.
- [37] P. R. Haddad and D. M. Pozar, "Anomalous mutual coupling between microstrip antennas," *IEEE Transactions on Antennas and Propagation*, vol. 42, no. 11, pp. 1545–1549, 1994.
- [38] T. Y. Wu, S. T. Fang, and K. L. Wong, "Printed diversity monopole antenna for WLAN operation," *Electronics Letters*, vol. 38, no. 25, pp. 1625–1626, 2002.
- [39] K. L. Wong, S. W. Su, and Y. L. Kuo, "A printed ultra-wideband diversity monopole antenna," *Microwave and Optical Technology Letters*, vol. 38, no. 4, pp. 257–259, 2003.
- [40] G. Chi, B. Li, and D. Qi, "Dual-band printed diversity antenna for 2.4/5.2-GHz WLAN application," *Microwave and Optical Technology Letters*, vol. 45, no. 6, pp. 561–563, 2005.

- [41] G. Mavridis, J. Sahalos, and M. Chryssomallis, "Spatial diversity two-branch antenna for wireless devices," *Electronics Letters*, vol. 42, no. 5, pp. 266–268, 2006.
- [42] Y. Ding, Z. Du, K. Gong, and Z. Feng, "A novel dual-band printed diversity antenna for mobile terminals," *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 7, pp. 2088–2096, 2007.
- [43] I. Kim, C. W. Jung, Y. Kim, and Y. E. Kim, "Low-profile wideband MIMO antenna with suppressing mutual coupling between two antennas," *Microwave and Optical Technology Letters*, vol. 50, no. 5, pp. 1336–1339, 2008.
- [44] S. Zhang, Z. Ying, J. Xiong, and S. He, "Ultrawideband MIMO/diversity antennas with a tree-like structure to enhance wideband isolation," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 1279–1282, 2009.
- [45] E. Antonino-Daviu, M. Gallo, B. Bernardo-Clemente, and M. Ferrando-Bataller, "Ultra-wideband slot ring antenna for diversity applications," *Electronics Letters*, vol. 46, no. 7, pp. 478–480, 2010.
- [46] A. Najam, Y. Duroc, and S. Tedjni, "UWB-MIMO antenna with novel stub structure," *Progress in Electromagnetics Research*, vol. 19, pp. 245–257, 2011.
- [47] M. S. Sharawi, S. S. Iqbal, and Y. S. Faouri, "An 800 MHz  $2 \times 1$  compact MIMO antenna system for LTE handsets," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 8, pp. 3128–3131, 2011.
- [48] J. F. Li, Q. X. Chu, and T. G. Huang, "A compact wideband MIMO antenna with two novel bent slits," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 2, pp. 482–489, 2012.
- [49] M. S. Sharawi, A. B. Numan, M. U. Khan, and D. N. Aloï, "A dual-element dual-band MIMO antenna system with enhanced isolation for mobile terminals," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 1006–1009, 2012.
- [50] C.-H. Wu, G.-T. Zhou, Y.-L. Wu, and T.-G. Ma, "Stub-loaded reactive decoupling network for two-element array using even–odd analysis," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 452–455, 2013.
- [51] L. Liu, S. W. Cheung, and T. I. Yuk, "Compact MIMO antenna for portable devices in UWB applications," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 8, pp. 4257–4264, 2013.
- [52] L. Liu, S. W. Cheung, and T. I. Yuk, "Compact multiple-input-multiple-output antenna using quasi-self-complementary antenna structures for ultrawideband applications," *IET Microwaves, Antennas and Propagation*, vol. 8, no. 13, pp. 1021–1029, 2014.
- [53] J. Ren, W. Hu, Y. Yin, and R. Fan, "Compact printed MIMO antenna for UWB applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1517–1520, 2014.
- [54] L. Kang, H. Li, X. Wang, and X. Shi, "Compact offset microstrip-fed MIMO antenna

- for band-notched UWB applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1754–1757, 2015.
- [55] M. G. N. Alsath and M. Kanagasabai, “Compact UWB monopole antenna for automotive communications,” *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 9, pp. 4204–4208, 2015.
- [56] S. Zhang and G. F. Pedersen, “Mutual coupling reduction for UWB MIMO antennas with a wideband neutralization line,” *IEEE Antenna and Wireless Propagation Letters*, vol. 15, pp. 166–169, 2016.
- [57] J. Zhu, B. Feng, B. Peng, L. Deng, and S. Li, “A dual notched band MIMO slot antenna system with Y-shaped defected ground structure for UWB applications,” *Microwave and Optical Technology Letters*, vol. 58, no. 3, pp. 626–630, 2016.
- [58] G.-S. Lin, C.-H. Sung, J.-L. Chen, L.-S. Chen, and M.-P. Houn, “Isolation improvement in UWB MIMO antenna system using carbon black film,” *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 222–225, 2017.
- [59] M. S. Khan, A.-D Capobianco, S. M. Asif, D. E. Anagnostou, R. M. Shubair, and B. D. Braaten, “A compact CSRR-enabled UWB diversity antenna,” *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 808–812, 2017.
- [60] A. Iqbal, O. A. Saraereh, A. W. Ahmad, and S. Bashir, “Mutual coupling reduction using F-shaped stubs in UWB-MIMO antenna,” *IEEE Access*, vol. 6, pp. 2755–2759, 2018.
- [61] S. R. Thummaluru, R. Kumar, and R. K. Chaudhary, “Isolation enhancement and radar cross section reduction of MIMO antenna with frequency selective surface,” *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 3, pp. 1595–1600, 2018.
- [62] R. Chandel, A. K. Gautam, and K. Rambabu, “Tapered fed compact UWB MIMO-diversity antenna with dual band-notched characteristics,” *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 4, pp. 1677–1684, 2018.
- [63] Z. Li, C. Yin, and X. Zhu, “Compact vivaldi antenna with dual band-notched characteristics,” *IEEE Access*, vol. 7, pp. 38696–38701, 2019.
- [64] A. A. Ghannad, M. Khalily, P. Xiao, R. Tafazolli, and A. A. Kishk, “Enhanced matching and vialess decoupling of nearby patch antennas for MIMO system,” *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 6, pp. 1066–1070, 2019.
- [65] L. Wang, Z. Du, H. Yang, R. Ma, Y. Zhao, X. Cui, and X. Xi, “Compact UWB MIMO antenna with high isolation using fence-type decoupling structure,” *IEEE Antenna and Wireless Propagation Letters*, vol. 18, no. 8, pp. 1641–1645, 2019.
- [66] R. Karimian, M. Soleimani, and S. M. Hashemi, “Tri-band four elements MIMO antenna system for WLAN and WiMAX application,” *Journal of Electromagnetic Waves and Applications*, vol. 26, pp. 2348–2357, 2012.
- [67] D. K. Ntaikos and T. V. Yioultsis, “Compact split-ring resonator-loaded multiple-

- input–multiple-output antenna with electrically small elements and reduced mutual coupling,” *IET Microwaves, Antennas and Propagation*, vol. 7, no. 6, pp. 421–429, 2013.
- [68] A. Moradikordalivand, T. A. Rahman, and M. Khalily, “Common elements wideband MIMO antenna system for Wi-Fi/LTE access point applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1601–1604, 2014.
- [69] S. Tripathi, A. Mohan, and S. Yadav, “A compact koch fractal UWB MIMO antenna with WLAN band-rejection,” *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1565–1568, 2015.
- [70] G. Srivastava and A. Mohan, “Compact MIMO slot antenna for UWB applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1057–1060, 2016.
- [71] R. Anitha, P. V. Vinesh, K. C. Prakash, P. Mohanan, and K. Vasudevan, “A compact quad element slotted ground wideband antenna for MIMO applications,” *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 10, pp. 4550–4553, 2016.
- [72] D. Sarkar and K. V. Srivastava, “A compact four element MIMO/diversity antenna with enhanced bandwidth,” *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2469–2472, 2017.
- [73] D. Sarkar and K. V. Srivastava, “Compact four-element SRR-loaded dual-band MIMO antenna for WLAN/WiMAX/WiFi/4G-LTE and 5G applications,” *Electronics Letters*, vol. 53, no. 25, pp. 1623–1624, 2017.
- [74] A. Boukarkar, X. Q. Lin, Y. Jiang, L. Y. Nie, P. Mei, and Y. Q. Yu, “A miniaturized extremely close-spaced four-element dual-band MIMO antenna system with polarization and pattern diversity,” *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 1, pp. 134–137, 2018.
- [75] S. Saxena, B. K. Kanaujia, S. Dwari, S. Kumar, and R. Tiwari, “MIMO antenna with built-in circular shaped isolator for sub-6 GHz 5G applications,” *Electronics Letters*, vol. 54, no. 8, pp. 478–480, 2018.
- [76] S. Pandit, A. Mohan, and P. Ray, “A compact four-element MIMO antenna for WLAN applications,” *Microwave and Optical Technology Letters*, vol. 60, no. 2, pp. 289–295, 2018.
- [77] A. A. R. Saad and H. A. Mohamed, “Conceptual design of a compact four-element UWB MIMO slot antenna array,” *IET Microwaves, Antennas and Propagation*, vol. 13, no. 2, pp. 1021–1029, 2019.
- [78] T. Alam, S. R. Thummaluru, and R. K. Chaudhary, “Integration of MIMO and cognitive radio for sub-6 GHz 5G applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 10, pp. 2021–2025, 2019.
- [79] R. Gómez-Villanueva and H. Jardón-Aguilar, “Compact UWB uniplanar four-port MIMO antenna array with rejecting band,” *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 12, pp. 2543–2547, 2019.

- 
- [80] A. Iqbal, A. Smida, A. J. Alazemi, M. I. Waly, N. K. Mallat, and S. Kim, "Wideband circularly polarized MIMO antenna for high data wearable biotelemetric devices," *IEEE Access*, vol. 8, pp. 17935–17944, 2020.
- [81] S. Saxena, B. K. Kanaujia, S. Dwari, S. Kumar, H. C. Choi, and K. W. Kim, "Planar four-port dual circularly-polarized MIMO antenna for sub-6 GHz band," *IEEE Access*, vol. 8, pp. 90779–90791, 2020.
- [82] A. Desai, C. D. Bui, J. Patel, T. Upadhyaya, G. Byun, and T. K. Nguyen, "Compact wideband four element optically transparent MIMO antenna for mm-wave 5G applications," *IEEE Access*, vol. 8, pp. 194206–194217, 2020.
- [83] R. Saleem, M. Bilal, K. B. Bajwa, and M. F. Shafique, "Eight-element UWB-MIMO array with three distinct isolation mechanisms," *Electronics Letters*, vol. 51, no. 4, pp. 311–313, 2015.
- [84] D. S. Kwon, S.-J. Lee, J.-W. Kim, B. K. Ahn, J.-W. Yu, and W.-S. Lee, "An eight-element compact low-profile planar MIMO antenna using LC resonance with high isolation," *Journal of Electromagnetic Engineering and Science*, vol. 16, no. 3, pp. 194–197, 2016.
- [85] D. Sibal, M. P. Abegaonkar, and S. K. Koul, "Easily extendable compact planar UWB MIMO antenna array," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2328–2331, 2017.
- [86] C. F. Ding, X. Y. Zhang, C.-D. Xue, and C.-Y.-D. Sim, "Novel pattern-diversity-based decoupling method and its application to multielement MIMO antenna," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 10, pp. 4976–4985, 2018.
- [87] S. P. Biswal and S. Das, "Eight-element-based MIMO antenna with CP behaviour for modern wireless communication," *IET Microwaves, Antennas and Propagation*, vol. 14, no. 1, pp. 45–52, 2019.
- [88] C. Yu, S. Yang, Y. Chen, W. Wang, L. Zhang, B. Li, and L. Wang, "A super-wideband and high isolation MIMO antenna system using a windmill-shaped decoupling structure," *IEEE Access*, vol. 8, pp. 115767–115777, 2020.
- [89] M. Ikram, N. Nguyen-Trong, and A. M. Abbosh, "Realization of a tapered slot array as both decoupling and radiating structure for 4G/5G wireless devices," *IEEE Access*, vol. 7, pp. 159112–159118, 2019.
- [90] M. Ikram, N. Nguyen-Trong, and A. M. Abbosh, "Common-aperture sub-6 GHz and millimeter-wave 5G antenna system," *IEEE Access*, vol. 8, pp. 199415–199423, 2020.
- [91] A. Mohanty and B. R. Behera, "Design and analysis of compact 8-port dual-element MIMO antenna for wireless applications utilizing classical electromagnetic CMA approach," *AEU International Journal of Electronics and Communications*, vol. 145, pp. 1–16, 2021.
- [92] J. Zhang, Z. Zheng, Y. Zhang, J. Xi, X. Zhao, and G. Gui, "3D MIMO for 5G NR: several observations from 32 to massive 256 antennas based on channel

- measurement,” *IEEE Communications Magazine*, vol. 56, no. 3, pp. 62–70, 2018.
- [93] S. S. Jehangir and M. S. Sharawi, “A miniaturized UWB biplanar yagi-like MIMO antenna system,” *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2320–2323, 2017.
- [94] N. O. Parchin, Y. I. A. Al-Yasir, A. H. Ali, I. Elfergani, J. M. Noras, J. Rodriguez, and R. A. Abd-Alhameed, “Eight-element dual-polarized MIMO slot antenna system for 5G smartphone applications,” *IEEE Access*, vol. 7, pp. 15612–15622, 2019.
- [95] S. R. Thummaluru, M. Ameen, and R. K. Chaudhary, “Four-port MIMO cognitive radio system for mid-band 5G applications,” *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 8, pp. 5634–5645, 2019.
- [96] G. Zhai, Z. N. Chen, and X. Qing, “Mutual coupling reduction of a closely spaced four-element MIMO antenna system using discrete mushrooms,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 10, pp. 3060–3067, 2016.
- [97] Y. Pan, Y. Cui, and R. L. Li, “Investigation of a triple-band multibeam MIMO antenna for wireless access point,” *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 4, pp. 1234–1241, 2016.
- [98] L. Liu, S. W. Cheung, and T. I. Yuk, “Compact MIMO antenna for portable UWB applications with band-notched characteristic,” *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 5, pp. 1917–1924, 2015.
- [99] Y. Li, W. Li, and W. Yu, “A multi-band/UWB MIMO/diversity antenna with an enhanced isolation using radial stub loaded resonator,” *Applied Computational Electromagnetics Society Journal*, vol. 28, no. 1, pp. 8–20, 2013.
- [100] L. Zhao, L. K. Yeung, and K.-L. Wu, “A coupled resonator decoupling network for two-element compact antenna arrays in mobile terminals,” *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 5, pp. 2767–2776, 2014.
- [101] F. Liu, J. Guo, L. Zhao, G.-L. Huang, Y. Li, and Y. Yin, “Dual-band metasurface-based decoupling method for two closely packed dual-band antennas,” *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 1, pp. 552–557, 2020.
- [102] J. Guo, F. Liu, L. Zhao, Y. Yin, G.-L. Huang, Y. Li, “Meta-surface antenna array decoupling designs for two linear polarized antennas coupled in H-plane and E-plane,” *IEEE Access*, vol. 7, pp. 100442–100452, 2019.
- [103] X. Zhao, F. Liu, Y. Liu, L. Zhao, and Y. Liu, “Compact meta-surface antenna array decoupling (MAAD) design for tightly coupled antennas,” *International Workshop on Antenna Technology (iWAT)*, pp. 73–76, 2019.
- [104] S. Luo, Y. Li, Y. Xia, and L. Zhang, “A low mutual coupling antenna array with gain enhancement using metamaterial loading and neutralization line structure,” *Applied Computational Electromagnetics Society Journal*, vol. 34, no. 3, pp. 411–418, 2019.
- [105] P. Garg and P. Jain, “Isolation improvement of MIMO antenna using a novel flower shaped metamaterial absorber at 5.5 GHz WiMAX band,” *IEEE Transactions on*

- Circuits and Systems II: Express Briefs*, vol. 67, no. 4, pp. 675–679, 2020.
- [106] K. Yu, Y. Li, and X. Liu, “Mutual coupling reduction of a MIMO antenna array using 3-D novel meta-material structures,” *Applied Computational Electromagnetics Society Journal*, vol. 33, no. 7, pp. 758–763, 2018.
- [107] T. Jiang, T. Jiao, and Y. Li, “A low mutual coupling MIMO antenna using periodic multi-layered electromagnetic band gap structures,” *Applied Computational Electromagnetics Society Journal*, vo. 33, no. 3, pp. 305–311, 2018.
- [108] G. Jing, Y. Liu, X. Zhao, L. Zhao, “Coupling reduction of antenna array in 5G MIMO frequency band below 6 GHz based on multi-feed technology,” *International Conference Electronic Information Communication Technology (ICEICT)*, pp. 710–712, 2019.
- [109] A. K. Gautam, S. Yadav, and K. Rambabu, “Design of ultra-compact UWB antenna with band-notched characteristics for MIMO applications,” *IET Microwaves, Antennas and Propagation*, vol. 12, no. 12, pp. 1895–1900, 2018.
- [110] M. S. Khan, A.-D. Capobianco, A. Iftikhar, R. M. Shubair, D. E. Anagnostou, and B. D. Braaten, “Ultra-compact dual-polarised UWB MIMO antenna with meandered feeding lines,” *IET Microwaves, Antennas and Propagation*, vol. 11, no. 7, pp. 997–1002, 2017.
- [111] R. Mathur and S. Dwari, “8-port multibeam planar UWB-MIMO antenna with pattern and polarisation diversity,” *IET Microwaves, Antennas and Propagation*, vol. 13, no. 13, pp. 2297–2302, 2019.
- [112] I. R. R. Barani, K.-L. Wong, Y.-X. Zhang, and W.-Y. Li, “Low-profile wideband conjoined open-slot antennas fed by grounded coplanar waveguides for  $4 \times 4$  5G MIMO operation,” *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 4, pp. 2646–2657, 2020.
- [113] A. Smida, A. Iqbal, M. Selmi, A. A. Althuwayb, and N. K. Mallat, “Varactor diode-based dual-band frequency tunable multiple-input multiple-output antenna,” *International Journal of RF and Microwave Computer-Aided Engineering*, vol 31, pp. 1–11, 2020.
- [114] I. Elfergani, A. Iqbal, C. Zebiri, A. Basir, J. Rodriguez, M. Sajedin, A. O. Pereira, W. Mshwat, R. Abd-Alhameed, and S. Ullah, “Low-profile and closely spaced four-element MIMO antenna for wireless body area networks,” *Electronics*, vol. 9, pp. 1–16, 2020.
- [115] A. K. Saurabh, P. S. Rathore, and M. K. Meshram, “Compact wideband four-element MIMO antenna with high isolation,” *Electronics Letters*, vol. 56, no. 3, pp. 117–119, 2020.
- [116] A. Ramachandran, S. V. Pushpakaran, M. Pezhholil, and V. Kesavath, “A four-port MIMO antenna using concentric square-ring patches loaded with CSRR for high

- isolation,” *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1196–1199, 2016.
- [117] S. Ghosh, T. N. Tran, and T. Le-Ngoc, “Dual-layer EBG-based miniaturized multi-element antenna for MIMO systems,” *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 8, pp. 3985–3997, 2014.
- [118] W. Wang, Y. Wu, W. Wang, and Y. Yang, “Isolation enhancement in dual-band monopole antenna for 5G applications,” *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 68, no. 6, pp. 1867–1871, 2021.
- [119] M. Bilal, R. Saleem, H. H. Abbasi, M. F. Shafique, and A. K. Brown, “An FSS-based nonplanar quad-element UWB-MIMO antenna system,” *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 987–990, 2017.
- [120] T. Shabbir, R. Saleem, S. S. Al-Bawri, M. F. Shafique, and M.T. Islam, “Eight-port metamaterial loaded UWB-MIMO antenna system for 3D system-in-package applications,” *IEEE Access*, vol. 8, pp. 106982–106992, 2020.
- [121] T. Shabbir, M.T. Islam, S. S. Al-Bawri, R. W. Aldhaheri, K. H. Alharbi, A. J. Aljohani, and R. Saleem, “16-Port nonplanar MIMO antenna system with near-zero-index (NZI) metamaterial decoupling structure for 5G applications,” *IEEE Access*, vol. 8, pp. 157946–157958, 2020.
- [122] M. S. Sharawi, “Current misuses and future prospects for printed multiple-input, multiple-output antenna systems,” *IEEE Antennas and Propagation Magazine*, vol. 59, no. 2, pp. 162–170, 2017.
- [123] H. Wong, K. K. So, and X. Gao, “Bandwidth enhancement of a monopolar patch antenna with V-shaped slot for car-to-car and WLAN communications,” *IEEE Transactions on Vehicular Technology*, vol. 65, no. 3, pp. 1130–1136, 2016.
- [124] S. Gao, L. Ge, D. Zhang, and W. Qin, “Low-profile dual-band stacked microstrip monopolar patch antenna for WLAN and car-to-car communications,” *IEEE Access*, vol. 6, pp. 69575–69581, 2018.
- [125] T. Mondal, S. Maity, R. Ghatak, and S. R. B. Chaudhuri, “Compact circularly polarized wide-beamwidth fern-fractal-shaped microstrip antenna for vehicular communication,” *IEEE Transactions on Vehicular Technology*, vol. 67, no. 6, pp. 5126–5134, 2018.
- [126] S. Wang, L. Zhu, G. Zhang, J. Yang, J. Wang, and W. Wu, “Dual-band dual-CP all-metal antenna with large signal coverage and high isolation over two bands for vehicular communications,” *IEEE Transactions on Vehicular Technology*, vol. 69, no. 1, pp. 1131–1135, 2020.
- [127] D. Potti, Y. Tusharika, M. G. N. Alsath, S. Kirubaveni, M. Kanagasabai, R. Sankararajan, S. Narendhiran, and P. B. Bhargav, “A novel optically transparent UWB antenna for automotive MIMO communications,” *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 7, pp. 3821–3828, 2021.

- [128] S. Yang, L. Liang, W. Wang, Z. Fang, and Y. Zheng, "Wideband gain enhancement of an AMC cavity-backed dual-polarized antenna," *IEEE Transactions on Vehicular Technology*, vol. 70, no. 12, pp. 12703–12712, 2021.
- [129] P. Bactavatchalame and K. Rajakani, "Compact broadband slot-based MIMO antenna array for vehicular environment," *Microwave and Optical Technology Letters*, vol. 62, pp. 2024–2032, 2020.
- [130] M. Saravanan, R. Kalidoss, B. Partibane, and K. S. Vishvakshenan, "Design of an interlocked four-port MIMO antenna for UWB automotive communications," *International Journal of Microwave and Wireless Technologies*, vol. 14, no. 2, pp. 239–246, 2022.
- [131] A. K. Dwivedi, A. Sharma, A. K. Singh, and V. Singh, "Circularly polarized quad-port MIMO dielectric resonator antenna with beam tilting feature for vehicular communication," *IETE Technical Review*, vol. 39, no. 2, pp. 389–401, 2022.
- [132] J.-K. Che, C.-C. Chen, and J. F. Locke, "A compact 4-channel MIMO 5G Sub-6 GHz/LTE/WLAN/V2X antenna design for modern vehicles," *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 11, pp. 7290–7297, 2021.
- [133] W. Wang, Z. Zhao, Q. Sun, X. Liao, Z. Fang, K. Y. See, and Y. Zheng, "Compact quad-element vertically-polarized high isolation wideband MIMO antenna for vehicular base station," *IEEE Transactions on Vehicular Technology*, vol. 69, no. 9, pp. 10000–10008, 2020.
- [134] W. Wang and Y. Zheng, "Wideband gain enhancement of a dual-polarized MIMO vehicular antenna," *IEEE Transactions on Vehicular Technology*, vol. 70, no. 8, pp. 7897–7907, 2021.
- [135] G. Artner, W. Kotterman, G. D. Galdo, and M. A. Hein, "Automotive antenna roof for cooperative connected driving," *IEEE Access*, vol. 7, pp. 20083–20090, 2019.
- [136] S. K. Palaniswamy, Y. P. Selvam, M. G. N. Alsath, M. Kanagasabai, S. Kingsly, and S. Subbaraj, "3-D eight-port ultrawideband antenna array for diversity applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 569–572, 2017.
- [137] M. S. Khan, F. Rigobello, B. Ijaz, E. Autizi, A. D. Capobianco, R. Shubair, and S. A. Khan, "Compact 3-D eight elements UWB-MIMO," *Microwave and Optical Technology Letters*, vol. 60, pp. 1967–1971, 2018.
- [138] S. Shakir, M. Bilal, S. M. Abbas, N. Saleem, Z. Rauf, R. A. Wagan, R. Saleem, and M. F. Shafique, "A compact 8-element 3D UWB diversity antenna system for off device installation," *IEEE Access*, vol. 9, pp. 44117–44127, 2021.
- [139] A. K. Saurabh and M. K. Meshram, "Wideband 20-elements 3D-MIMO antenna for localization system," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 69, no. 2, pp. 409–413, 2022.
- [140] C.-Y.-D. Sim, H.-Y. Liu, and C.-J. Huang, "Wideband MIMO antenna array design for future mobile devices operating in the 5G NR frequency bands n77/n78/n79 and

- LTE band 46,” *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 1, pp. 74–78, 2020.
- [141] European Telecommunications Standards Institute (ETSI), *5G; NR; User Equipment (UE) Radio Transmission and Reception; Part 2: Range 2 Standalone (3GPP TS 38.101-2 Version 15.2.0 Release 15)*, ETSI TS 138 101–2, V15.2.0 (2018–07), Reference: RTS/TSGR-0438101-2vf20, July 2018.
- [142] L. Sun, Y. Li, Z. Zhang, and Z. Feng, “Wideband 5G MIMO antenna with integrated orthogonal-mode dual-antenna pairs for metal-rimmed smartphones,” *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 4, pp. 2494–2503, 2020.
- [143] Z. Xu and C. Deng, “High-isolated MIMO antenna design based on pattern diversity for 5G mobile terminals,” *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 3, pp. 467–471, 2020.
- [144] L. Sun, Y. Li, Z. Zhang, and H. Wang, “Self-decoupled MIMO antenna pair with shared radiator for 5G smartphones,” *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 5, pp. 3423–3432, 2020.
- [145] A. Zhao and Z. Ren, “Size reduction of self-isolated MIMO antenna system for 5G mobile phone applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 1, pp. 152–156, 2019.
- [146] W. Jiang, B. Liu, Y. Cui, and W. Hu, “High-isolation eight-element MIMO array for 5G smartphone applications,” *IEEE Access*, vol. 7, pp. 34104–34112, 2019.
- [147] W. Hu, L. Qian, S. Gao, L.-H. Wen, Q. Luo, H. Xu, X. Liu, Y. Liu, and W. Wang, “Dual-band eight-element MIMO array using multi-slot decoupling technique for 5G terminals,” *IEEE Access*, vol. 7, pp. 153910–153920, 2019.
- [148] L. Sun, Y. Li, and Z. Zhang, “Wideband decoupling of integrated slot antenna pairs for 5G smartphones,” *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 4, pp. 2386–2391, 2021.
- [149] L. Sun, Y. Li, and Z. Zhang, “Wideband integrated quad-element MIMO antennas based on complementary antenna pairs for 5G smartphones,” *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 8, pp. 4466–4474, 2021.
- [150] B. Cheng and Z. Du, “A wideband low-profile microstrip MIMO antenna for 5G mobile phones,” *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 2, pp. 1476–1481, 2022.
- [151] B. Cheng and Z. Du, “Dual polarization MIMO antenna for 5G mobile phone applications,” *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 7, pp. 4160–4165, 2021.
- [152] D. Q. Liu, H. J. Luo, M. Zhang, H. L. Wen, B. Wang, and J. Wang, “An extremely low-profile wideband MIMO antenna for 5G smartphones,” *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 9, pp. 5772–5780, 2019.

- [153] M. Khalily, R. Tafazolli, P. Xiao, and A. A. Kishk, "Broadband mm-wave microstrip array antenna with improved radiation characteristics for different 5G applications," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 9, pp. 4641–4647, 2018.
- [154] C.-X. Mao, M. Khalily, P. Xiao, T. W. C. Brown, and S. Gao, "Planar sub-millimeter-wave array antenna with enhanced gain and reduced sidelobes for 5G broadcast applications," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 1, pp. 160–168, 2019.
- [155] J. Kowalewski, J. Eisenbeis, A. Jauch, J. Mayer, M. Kretschmann, and T. Zwick, "A mmW broadband dual-polarized dielectric resonator antenna based on hybrid modes," *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 7, pp. 1068–1072, 2020.
- [156] S. J. Yang, Y. M. Pan, L.-Y. Shi, and X. Y. Zhang, "Millimeter-wave dual-polarized filtering antenna for 5G application," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 7, pp. 5114–5121, 2020.
- [157] Y. Zhang, J.-Y. Deng, M.-J. Li, D. Sun, and L.-X. Guo, "A MIMO dielectric resonator antenna with improved isolation for 5G mm-wave applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 4, pp. 747–751, 2019.
- [158] M. Jada, I. A. Shah, and H. Yoo, "Integration of Sub-6-GHz and mm-wave bands with a large frequency ratio for future 5G MIMO applications," *IEEE Access*, vol. 9, pp. 11241–11251, 2021.
- [159] T.-Q. Fan, B. Jiang, R. Liu, J. Xiu, Y. Lin, and H. Xu, "A novel double U-slot microstrip patch antenna design for low-profile and broad bandwidth applications," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 4, pp. 2543–2549, 2022.



# Publications

## Author's Relevant Publications

### Journals:

1. **Arun Kumar Saurabh** and Manoj Kumar Meshram, "Compact sub-6 GHz 5G-multiple-input-multiple-output antenna system with enhanced isolation," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 30, no. 8, pp. 1–11, 2020.
2. **Arun Kumar Saurabh** and Manoj Kumar Meshram, "Wideband 20-elements 3D-MIMO antenna for localization system," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 69, no. 2, pp. 409–413, 2022.
3. **Arun Kumar Saurabh** and Manoj Kumar Meshram, "Wideband 32-element 3D-MIMO antenna for vehicular applications," *IEEE Transactions on Vehicular Technology*, [Under Review].
4. **Arun Kumar Saurabh**, Rahul Dubey, and Manoj Kumar Meshram, "Wideband eight-element MIMO antenna with band-dispensation characteristics," *AEU International Journal of Electronics and Communications*, vol. 155, pp. 1–11, 2022.
5. **Arun Kumar Saurabh** and Manoj Kumar Meshram, "Integration of sub-6 GHz and mm-wave antenna for higher-order 5G-MIMO system," *IEEE Transactions on Circuits and Systems II: Express Briefs*, 2022, DOI: [10.1109/TCSII.2022.3197598](https://doi.org/10.1109/TCSII.2022.3197598).

---

## Other Relevant Publications

### Journals:

1. **Arun Kumar Saurabh**, Praveen Singh Rathore, and Manoj Kumar Meshram, “Compact wideband four-element MIMO antenna with high isolation,” *Electronics Letters*, vol. 56, no. 3, pp. 117–119, 2020.
2. **Arun Kumar Saurabh**, Praveen Singh Rathore, Rahul Dubey, and Manoj Kumar Meshram, “Compact eight-element 5G-MIMO antenna utilized for higher-order MIMO system,” *Journal of Electromagnetic Waves and Applications*, [Under Review].

### Conferences/Symposium:

1. **Arun Kumar Saurabh** and Manoj Kumar Meshram, “Compact quad-element triple-band MIMO antenna for WLAN/WiMAX applications,” *IEEE Indian Conference on Antenna and Propagation (InCAP)*, December 16–19, 2018, Hyderabad, India.
2. **Arun Kumar Saurabh**, Saurabh Kumar Srivastava, and Manoj Kumar Meshram, “CSRR loaded compact quad-element MIMO antenna for wireless applications,” *IEEE MTT-S International Microwave and RF Conference (IMaRC)*, December 17–19, 2021, IIT Kanpur, India.
3. **Arun Kumar Saurabh**, Saurabh Kumar Srivastava, and Manoj Kumar Meshram, “Compact eight-element MIMO antenna for UWB applications,” *IEEE MTT-S & AP-S Microwaves, Antennas and Propagation Conference (MAPCON)*, December 12–16, 2022, Bangalore, India [Under Review].