

REFERENCE

- [1]. Wollschlaeger, M., Sauter, T. and Jasperneite, J. (2017) “*The Future of Industrial Communication: Automation Networks in the era of the Internet of Things and Industry 4.0*”, IEEE Industrial Electronics Magazine, 11(1), pp. 17–27. doi:10.1109/mie.2017.2649104. 4.
- [2]. Liu, D. et al. (2017) “*What will 5G antennas and propagation be?*”, IEEE Transactions on Antennas and Propagation, 65(12), pp. 6205–6212. doi:10.1109/tap.2017.2774707.
- [3]. Ilderem, V., “The technology underpinning 5G,” *Nature Electronics*, Vol. 3, No. 1, 5-6, 2020, doi:10.1038/s41928-019-0363-6.
- [4]. Médard, M., “Is 5 just what comes after 4?,” *Nature Electronics*, Vol. 3, No. 1, 2{4, 2020, doi:10.1038/s41928-019-0361-8.
- [5]. D. Huang, Z. Du and Y. Wang, “A Quad-Antenna System for 4G/5G/GPS Metal Frame Mobile Phones,” in IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 8, pp. 1586-1590, Aug. 2019, DOI: 10.1109/LAWP.2019.2924322
- [6]. D. Rusdiyanto and F. Y. Zulkifli, “Dual Band Circularly Polarized Microstrip Antenna Fed By Inverted-L Shaped With A Stub for GPS And WLAN Application,” 2019 11th International Conference on Information Technology and Electrical Engineering (ICITEE), Pattaya, Thailand, 2019, pp. 1-4, DOI: 10.1109/ICITEED.2019.8930001
- [7]. A. Baratè, G. Haus, L. A. Ludovico, and E. Pagani, “5G Technology For Music Education: A Feasibility Study,” vol. 14, no. 1, pp. 31–52.
- [8]. 5G basics (2017) ITU. Available at: <http://handle.itu.int/11.1002/pub/810ba6ee-en> (Accessed: 12 March 2024).
- [9]. Hasan, Md.M. et al. (2022) “*Gain and isolation enhancement of a wideband MIMO antenna using metasurface for 5G sub-6 ghz communication systems*”, Scientific Reports, 12(1). doi:10.1038/s41598-022-13522-5.
- [10]. GSMA. (2024, January). 5G Spectrum Positions. Available: <https://www.gsma.com/spectrum/wp-content/uploads/2019/02/5G-Spectrum-Positions-InfoG.pdf>
- [11]. Racha, G. et al. (2025). Design and performance analysis of digitally controlled multi-mode multi-band power amplifier for Sub-6 GHz applications. e-Prime -

- Advances in Electrical Engineering Electronics and Energy, 11, 100888.
<https://doi.org/10.1016/j.prime.2024.100888>
- [12]. How does Wider Spectrum The 5G Power? - Moniem-Tech. (2022, November 19). Moniem-Tech. <https://moniem-tech.com/questions/how-does-wider-spectrum-the-5g-power/> (Accessed: 24 January 2025).
- [13]. Benchmarking the Global 5G Experience – Ian Fogg. (2023, June 20). Opensignal. <https://www.opensignal.com/2023/06/30/benchmarking-the-global-5g-experience-june-2023> (Accessed: 24 January 2025).
- [14]. Siaran Pers no. 14/HM/KOMINFO/01/2022 Tentang Menkominfo tegaskan frekuensi 5g di Indonesia tak Ganggu Penerbangan. Available at: https://www.kominfo.go.id/content/detail/39470/siaran-pers-no-14hmkominfo012022-tentang-menkominfo-tegaskan-frekuensi-5g-di-indonesia-tak-ganggu-penerbangan/0/siaran_pers (Accessed: 12 July 2024).
- [15]. Roadmaps for awarding 5G Spectrum: A focus on Indonesia. Available at: https://www.gsma.com/connectivity-for-good/spectrum/wp-content/uploads/2022/09/spec_indonesia_mini_roadmap_07_22.pdf (Accessed: 12 July 2024).
- [16]. Seberapa Kuatkah Sinyal 5G? (2022) Telkomsel. Available at: <https://www.telkomsel.com/support/faq/seberapa-kuatkah-sinyal-5g> (Accessed: 12 July 2024).
- [17]. GSMA. 5G Spectrum GSMA Public Policy Position. 2022. Available at: <https://www.gsma.com/connectivity-for-good/spectrum/wp-content/uploads/2022/06/5G-Spectrum-Positions.pdf>
- [18]. Bellekhiri, A. *et al.* (2022) ‘A new design of 5G planar antenna with enhancement of the bandwidth and the gain using metasurface’, *E3S Web of Conferences*, 351, p. 01054. doi:10.1051/e3sconf/202235101054.
- [19]. A. Bilal *et al.*, "Metasurface Superstrate for 5G Bandwidth and Gain Enhancement," 2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI), Denver, CO, USA, 2022, pp. 247-248, doi: 10.1109/AP-S/USNC-URSI47032.2022.9887231.
- [20]. Kumar, G. *et al.* (2023) ‘Gain and Bandwidth Enhancement Using NZRI – Metasurface’, *IETE Journal of Research*, 69(11), pp. 7760–7768. doi: 10.1080/03772063.2022.2055662.

- [21]. Araújo, F.F. *et al.* (2021) 'Bandwidth enhancement of microstrip patch antenna using metasurface', *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, 20(1), pp. 105–117. doi:10.1590/2179-10742021v20i1959.
- [22]. M. Abdullah, A. Altaf, M. R. Anjum, Z. A. Arain, A. A. Jamali, M. Alibakhshikenari, F. Falcone, and E. Limiti, "Future smartphone: MIMO antenna system for 5G mobile terminals," *IEEE Access*, vol. 9, pp. 91593-91603, 2021.
- [23]. Misra, D. (2004). Radio-Frequency and Microwave Communication Circuits: Analysis and design. In *John Wiley eBooks*. <http://ci.nii.ac.jp/ncid/BA52372872>
- [24]. Lahiri, Basudev (2010) Split Ring Resonator (SRR) based metamaterials. PhD thesis, University of Glasgow.
- [25]. Malik, P.K., Padmanaban, S. and Holm-Nielsen, J.B. (2021) Microstrip antenna design for wireless applications [Preprint]. doi:10.1201/9781003093558.
- [26]. Das, H., Sharma, M., Xu, Q. (2022). Microstrip Antenna: An Overview and Its Performance Parameter. In: Malik, P.K., Lu, J., Madhav, B.T.P., Kalkhambkar, G., Amit, S. (eds) *Smart Antennas*. EAI/Springer Innovations in Communication and Computing. Springer, Cham. https://doi.org/10.1007/978-3-030-76636-8_1
- [27]. Rana, Md.S. *et al.* (2023a) 'Design, simulation, and analysis of microstrip patch antenna for wireless applications operating at 3.6 GHz', *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, 21(5), p. 957. doi:10.12928/telkomnika.v21i5.24813.
- [28]. Kasabegoudar, V.G. and Reddy, P. (2022) 'A review of low profile single layer microstrip antennas', *International Journal of Electrical and Electronic Engineering & Telecommunications*, pp. 122–131. doi:10.18178/ijeetc.11.2.122-131.
- [29]. Bukhari, S.S.; Vardaxoglou, J.; Whittow, W. A Metasurfaces Review: Definitions and Applications. *Appl. Sci.* 2019, 9, 2727. <https://doi.org/10.3390/app9132727>
- [30]. Kaur, P., Bansal, S., & Kumar, N. (2022). SRR metamaterial-based broadband patch antenna for wireless communications. *Journal of Engineering and Applied Science*, 69(1). <https://doi.org/10.1186/s44147-022-00103-6>

- [31]. Saktioto et al. (2021). Improvement of low-profile microstrip antenna performance by hexagonal-shaped SRR structure with DNG metamaterial characteristic as UWB application. *Alexandria Engineering Journal*, 61(6), 4241–4252. <https://doi.org/10.1016/j.aej.2021.09.048>
- [32]. Abdulkarim, et al. (2021). Utilization of a triple hexagonal split ring resonator (SRR) based metamaterial sensor for the improved detection of fuel adulteration. *Journal of Materials Science Materials in Electronics*, 32(19), 24258–24272. <https://doi.org/10.1007/s10854-021-06891-6>
- [33]. Sahandabadi, S., & Makki, S. V. A. (2019). Mutual coupling reduction using complementary of SRR with wire MNG structure. *Microwave and Optical Technology Letters*, 61(5), 1231–1234. <https://doi.org/10.1002/mop.31717>
- [34]. Sagadevan, K., Kumar, D. S., & Rajagopalan, S. (2021). The design of Split Ring Resonator (SRR) based Terahertz Bandpass filter and comparison of various types of filters. *Journal of Physics Conference Series*, 1717(1), 012052. <https://doi.org/10.1088/1742-6596/1717/1/012052>
- [35]. Paul, J. J., Rekh, A. S., & T, S. P. (2020). Study and analysis of various SRR patch structures for energy harvesting applications. 2022 7th International Conference on Communication and Electronics Systems (ICCES), 326–329. <https://doi.org/10.1109/icces48766.2020.9138062>
- [36]. J.C. Tie, D. R. Smith, and L. Ruopeng, *Metamaterials Theory, Design, and Applications*. New York, NY, USA: Springer, 2010.
- [37]. M. F. Wirahilmi, Edwar, F. K. Lumbantobing, L. Olivia Nur, A. F. Sendyartha and B. Setia Nugroho, "Double Layer Metasurface for Gain Enhancement of 5G Antenna," 2023 IEEE International Symposium On Antennas And Propagation (ISAP), Kuala Lumpur, Malaysia, 2023, pp. 1-2, doi: 10.1109/ISAP57493.2023.10388781.
- [38]. Z. Yang et al., "Metasurface-based wideband, low-profile, and high-gain antenna", *IET Microwaves, Antennas & Propagation*, vol. 13, no. 4, pp. 436 – 441, 2019.
- [39]. Glybovski, S.B.; Tretyakov, S.A.; Belov, P.A.; Kivshar, Y.S.; Simovski, C.R. *Metasurfaces: From microwaves to visible*. *Phys. Rep.* 2016, 634, 1–72.
- [40]. Ranjbar-Mohammadi, M., Yousefi, E. Fabrication of a dye removal system through electrospun of TiO₂/Nylon-6 nanocomposite on three-dimensional

spacer fabrics. *Polym. Bull.* **79**, 2953–2967 (2022).
<https://doi.org/10.1007/s00289-021-03645-6>

- [41]. C. M. Saleh, E. Almajali, A. Jarndal, J. Yousaf, S. S. Alja' Afreh and R. E. Amaya, "Wideband 5G Antenna Gain Enhancement Using a Compact Single-Layer Millimeter Wave Metamaterial Lens," in *IEEE Access*, vol. 11, pp. 14928-14942, 2023, doi:10.1109/ACCESS.2023.3244401.
- [42]. Fadhil, T.Z. et al. (2022) 'A beam-split metasurface antenna for 5G applications', *IEEE Access*, 10, pp. 1162–1174. doi:10.1109/access.2021.3137324
- [43]. Surendra Loya, and Habibulla Khan, "Complementary Split Ring Resonator Based Massive MIMO Antenna System for 5G Wireless Applications," *Progress In Electromagnetics Research C*, Vol. 116, 81-93, 2021. doi:10.2528/PIERC21072802
- [44]. Jalil, M.E. et al. (2021) 'High capacity and miniaturized flexible chipless RFID tag using modified complementary split ring resonator', *IEEE Access*, 9, pp. 33929–33943. doi:10.1109/access.2021.3061792.
- [45]. Dase, S. (2022). *Antena dan Propagasi: Teori dan Praktik*. Penerbit Andi.
- [46]. Balanis, Constantine A. *Antenna Theory Analysis and Design*. 3rd ed., Hoboken, John Wiley & Sons, Cop, 2005.
- [47]. Sten, .J., Hujanen, .A. Notes on the quality factor and bandwidth of radiating systems. *Electr Eng* 84, 189–195 (2002). <https://doi.org/10.1007/s00202-002-0122-x>
- [48]. Yaghjian, A. D. (2025). Fundamentals of antenna bandwidth and quality factor. arXiv (Cornell University). <https://doi.org/10.48550/arxiv.2501.03146>