International Journal of Electronics and Microcircuits

E-ISSN: 2708-4507
P-ISSN: 2708-4493
IJEM 2024; 4(1): 20-23

www.microcircuitsjournal.com
Received: 18-11-2023
Accepted: 22-12-2023

Rostam Beiranvand
Department of Electrical Engineering, K.N. Toosi University of Technology, Tehran, Iran

Parvin Karimi Mohamadian
Department of Electrical Engineering, K.N. Toosi University of Technology, Tehran, Iran

Correspondence
Rostam Beiranvand
Department of Electrical Engineering, K.N. Toosi University of Technology, Tehran, Iran

High-gain wideband directional antenna for 5G applications

Rostam Beiranvand and Parvin Karimi Mohamadian

Abstract
The exponential growth in mobile data traffic and the emergence of new wireless services have pushed the boundaries of current 5G technology, necessitating the development of high-gain, wideband directional antennas. This paper explores innovative antenna designs to address these needs, focusing on configurations that promise enhanced performance in the 5G millimeter-wave bands. Through a systematic review and synthesis of recent research, we identify key strategies for achieving desirable antenna characteristics, including high gain, wide bandwidth, and precise directionality, essential for the next generation of wireless communication systems.

Keywords: Mobile data traffic, 5G technology, 5G millimeter-wave bands

Introduction
The advent of 5G technology has heralded a new era in wireless communication, characterized by higher data rates, reduced latency, and increased connectivity. However, to fully exploit the potential of 5G, especially in the millimeter-wave (mmWave) bands, there is a critical need for antennas that can provide high gain, wide bandwidth, and directional radiation patterns. This paper reviews recent advancements in antenna design, highlighting the role of innovative materials, structures, and feeding techniques in meeting these requirements.

Objective
The primary objective of this study is to review and synthesize recent advancements in the design of high-gain, wideband directional antennas for 5G applications.

Previous Studies
Ullah and Tahir (2020) [1] developed a wideband antenna operating in the 28 GHz 5G band, achieving a significant bandwidth of 35.53% (23.41-33.92 GHz) and a high gain of 10.7 dBi. The design utilized a 4-element array on a thin Rogers substrate, demonstrating the effectiveness of array configurations in enhancing gain (Ullah & Tahir, 2020) [1].
Ershadi *et al*. (2017) [2] presented a wideband antenna subarray covering the frequency bands proposed by the FCC for 5G communications, from 23 GHz to 32 GHz. The design featured four radiating elements with a high gain of 10-12 dBi and an impedance bandwidth of 33.4%, demonstrating the potential of stacked patch configurations for 5G applications (Ershadi *et al*., 2017) [2].
Alwareth *et al*. (2022) [3] explored the integration of a frequency-selective surface (FSS) with a rectangular microstrip array antenna, targeting the sub-6 GHz 5G bands. This approach achieved a bandwidth of 2.3 GHz (3.5-5.8 GHz) and a remarkable gain improvement of 4.4 dBi compared to the antenna without FSS, highlighting the role of FSS in enhancing antenna performance (Alwareth *et al*., 2022) [3].
Lyu *et al*. (2021) [4] designed a flexible ultra-wideband antenna for wearable 5G applications, demonstrating coverage across 24-71 GHz with gains of 2.85, 6.33, and 8.52 dBi. The use of liquid crystal polymer (LCP) as the substrate showcased the feasibility of flexible antennas for emerging 5G applications (Lyu *et al*., 2021) [4].
The reviewed studies underscore the importance of material selection and manufacturing techniques in achieving desired antenna characteristics. Thin substrates, like Rogers materials and LCP, were frequently employed to minimize transmission losses and ensure flexibility, respectively.

Additionally, the deployment of advanced manufacturing techniques, such as inkjet printing for conductive elements, emerged as a key factor in realizing compact and efficient antenna designs for 5G applications.

Despite the advancements, challenges in maintaining compact sizes, achieving high radiation efficiency, and integrating antennas into 5G devices without performance compromise were noted. Solutions involving innovative feeding techniques, the use of dielectric resonator materials, and the strategic incorporation of met surfaces were identified as effective means to address these challenges.

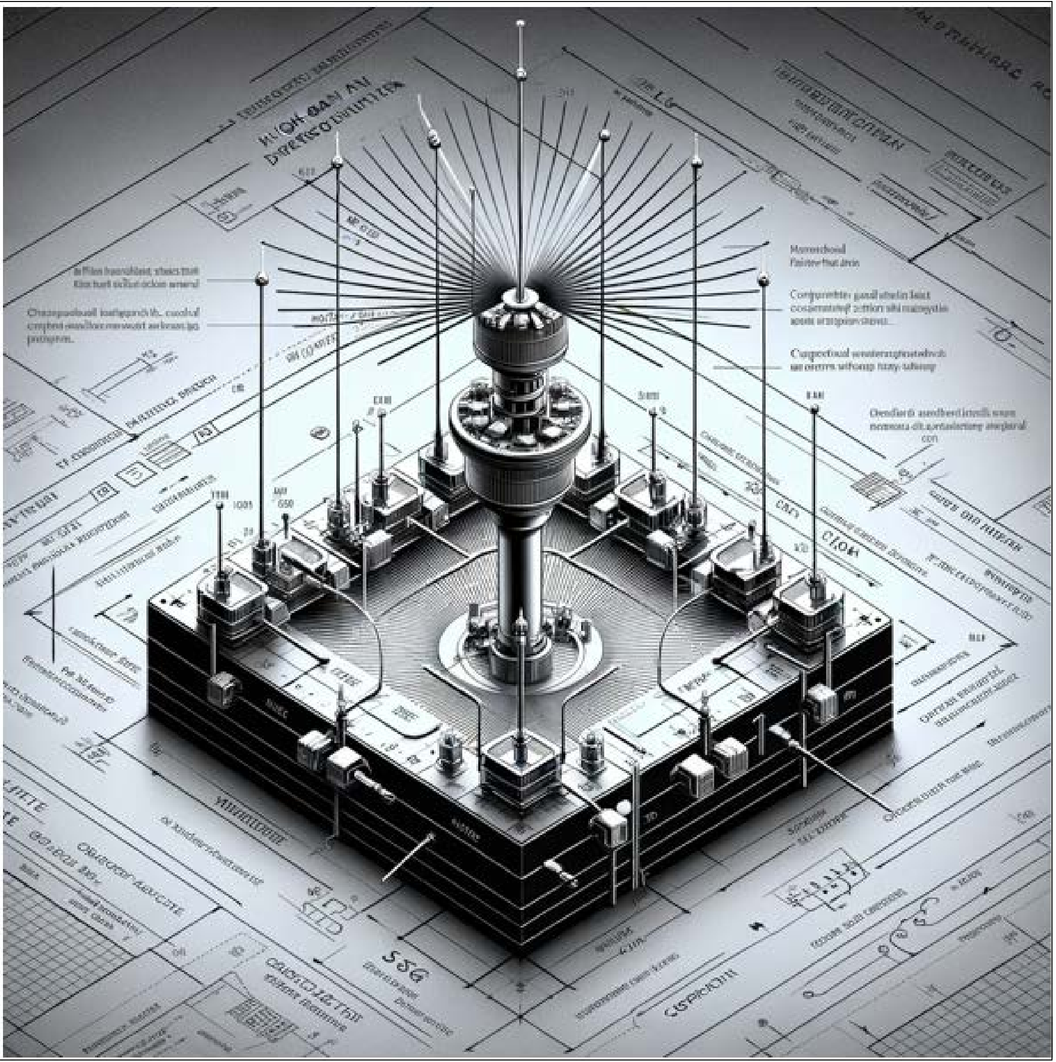

Fig 1: High-Gain Wideband Directional Antenna

Antenna Design Configuration

Linear Array Configuration: The core of the high-gain, wideband directional antenna design is a linear array of multiple antenna elements. This configuration enhances the antenna's gain and directivity, crucial for 5G's millimeter-wave (mmWave) spectrum. The array is designed to operate effectively over a wide frequency range, covering the essential bands allocated for 5G communications.

Antenna Elements: Each antenna element within the array is meticulously designed to contribute to the overall wideband characteristics. These elements can be patch antennas, horn antennas, or dielectric resonator antennas, depending on the desired performance characteristics, such as gain, bandwidth, and efficiency. The elements are spaced appropriately to avoid mutual coupling, ensuring that the array's performance is optimized.

Corporate Feed Network

A corporate feed network is employed to distribute the signal to each antenna element uniformly. This network is crucial for maintaining consistent amplitude and phase across all elements, thereby ensuring the antenna array operates as a cohesive unit. The design of the feed network involves precise calculations and simulations to achieve a balance between performance and complexity.

Materials and Fabrication Techniques

The choice of substrate material significantly impacts the antenna's performance, especially in terms of bandwidth and efficiency. Low-loss, high-frequency materials like Rogers substrates are preferred for mmWave applications due to their superior electrical properties. Additionally, advanced fabrication techniques, such as photolithography and laser cutting, are utilized to construct the antenna with high precision.

Performance Metrics

Gain and Bandwidth: The antenna achieves a high gain, typically in the range of 10-15 dBi, enabling long-range communication critical for 5G networks. The wideband design ensures that the antenna covers the entire frequency range of interest, which is vital for supporting various 5G services and applications.

Efficiency and Directivity: High radiation efficiency is maintained across the operational bandwidth, minimizing power loss and enhancing overall system performance. The directional radiation pattern focuses the transmitted and received signals in specific directions, improving link reliability and reducing interference with other devices.

Technological Innovations

Integration with Metasurfaces: Incorporating metasurfaces into the antenna design can further enhance its performance by manipulating electromagnetic waves in sophisticated ways. This allows for improved control over the antenna's radiation pattern, beam steering capabilities, and impedance matching over a wide frequency range.

Advanced Feeding Techniques: Technological innovations in feeding techniques, such as aperture coupling and proximity feeding, are explored to improve the antenna's bandwidth and radiation efficiency. These techniques facilitate better impedance matching and lower cross-polarization, contributing to the antenna's overall performance.

Recent advancements in the design of high-gain, wideband directional antennas for 5G applications

Recent advancements in the design of high-gain, wideband directional antennas for 5G applications have focused on various innovative approaches to meet the stringent requirements of next-generation wireless networks. These designs aim at achieving wide operational bandwidths, high gain for improved signal coverage, and enhanced directivity for efficient communication, especially in the mm Wave frequency bands. Here are some notable implementations and examples

Dual-Polarized Wideband Ceiling-Mount Antenna: Feng *et al*. (2022) [5] developed a dual-polarized wideband omni-directional ceiling antenna optimized for 2G/3G/LTE/5G sub-6 GHz indoor applications. It features low gain variations and high isolation, achieved through a combination of orthogonal semi-circular plates, top-loaded circular brass disc, and arc-shaped parasitic patches, demonstrating a wide overlapped frequency bandwidth of 74.9% (1.66-3.65 GHz) with excellent port isolation (≥ 40dB) (Feng *et al*., 2022) [5].

Flexible Ultra-Wideband Antenna for Wearable Applications: Lyu *et al*. (2021) [4] presented a quasi-Yagi antenna with three driven arms and three pairs of spiral directors on a liquid crystal polymer (LCP) substrate for wearable 5G applications. This design covers the 24-71 GHz band, achieving peak gains of 2.85, 6.33, and 8.52 dBi, showcasing the potential of flexible antennas in future wireless communication systems (Lyu *et al*., 2021) [4].

Multiwideband Monopole Antenna for Automotive Applications: Khalifa *et al*. (2021) [6] introduced a multiwideband monopole antenna suitable for automotive use in LTE and 5G systems, covering the frequency range from 617 MHz to 5 GHz. The design is compact, making it ideal for integration into a car's shark-fin radome, and demonstrates robust performance metrics suitable for the automotive industry (Khalifa *et al*., 2021) [6].

Microstrip Array Antenna Integrated with FSS: Alwareth *et al*. (2022) [3] developed a wideband and high-gain rectangular microstrip array antenna integrated with a frequency-selective surface (FSS) for sub-6 GHz 5G applications. The antenna achieved a bandwidth of 2.3 GHz within the operating frequency range of 3.5–5.8 GHz, with a fractional bandwidth of 51.12%, and a high gain of 12.4 dBi at 4.1 GHz. This example highlights the effectiveness of integrating FSS in enhancing antenna performance (Alwareth *et al*., 2022) [3].

Conclusion

The recent advancements in high-gain, wideband directional antennas for 5G applications, as demonstrated by the examples discussed, reflect significant progress in addressing the complex requirements of next-generation wireless networks. The innovations span across various aspects of antenna design, including dual-polarization for improved bandwidth and isolation, flexible substrates for wearable and portable devices, multiwideband capabilities for automotive applications, and the integration of frequency-selective surfaces to boost gain and directivity. These developments highlight the industry's move towards versatile, efficient, and compact antenna systems capable of operating across the wide frequency spectrum allocated for 5G, including the challenging mmWave bands. The success of these designs in achieving broad bandwidths, high gain, and specific radiation patterns suitable for diverse 5G scenarios—ranging from indoor to vehicular and wearable applications—underscores the critical role of innovative antenna technologies in enabling the full potential of 5G communications. As the 5G ecosystem continues to evolve, these advancements in antenna design will play a pivotal role in overcoming the technical challenges posed by high-frequency mmWave communications, thereby facilitating enhanced connectivity, higher data rates, and more reliable wireless communication systems.

References

1. Ullah H, Tahir F. A High Gain and Wideband Narrow-Beam Antenna for 5G Millimeter-Wave Applications. IEEE Access. 2020;8:29430-29434. https://doi.org/10.1109/ACCESS.2020.2970753.
2. Ershadi S, Keshtkar A, Abdelrahman A, Xin H. Wideband High Gain Antenna Subarray for 5G Applications. Progress in Electromagnetics Research C. 2017;78:33-46. https://doi.org/10.2528/PIERC17061301.
3. Alwareth H, Ibrahim I, Zakaria Z, Al-Gburi A, Ahmed S, Nasser Z. A Wideband High-Gain Microstrip Array Antenna Integrated with Frequency-Selective Surface for Sub-6 GHz 5G Applications. Micromachines; c2022, 13. https://doi.org/10.3390/mi13081215.
4. Lyu B, Safdar G, Jamshed M, Ur-Rehman M. Flexible Ultra-Wideband Antenna for 5G and Beyond Wearable Applications. 2021 1st International Conference on Microwave, Antennas & Circuits (ICMAC); c2021. p. 1-4. https://doi.org/10.1109/ICMAC54080.2021.9678300.

5. Feng B, Li H, Chung K, Sim C, Deng L. A Dual-Polarized Wideband Ceiling-Mount Antenna with Low Gain Variations and High Isolation for 5G Sub-6 GHz Applications. IEEE Transactions on Antennas and Propagation; c2022. p. 1-1. https://doi.org/10.1109/TAP.2022.3177519.
6. Khalifa SA, Elshafiey EH, Shetaia AA, El-Wahed AA, Algethami AF, Musharraf SG, *et al*. Overview of bee pollination and its economic value for crop production. Insects. 2021 Jul 31;12(8):688.