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*Editorial*

# Recent Advances in Antenna Design for 5G Heterogeneous Networks

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Fifth-generation will support significantly faster mobile broadband speeds, low latency, and reliable communications, as well as enabling the full potential of the Internet of Things (IoT). This will open up the possibility for new services, such as tactile communications, smart manufacturing and cities, and enhanced broadband connectivity. Over the last years, industries and the academic community both have implemented tremendous efforts to bring these systems into the real world. In fact, the 5G system has been tested and deployed in several countries; however, this upgrade only exploits a small portion of the huge potential of 5G system. This is because the system still uses the sub-6 GHz band, i.e., the lower microwave frequency ranges between 3.1–3.55 and 3.7–4.2 GHz in the United States, 3.4–3.8 GHz in Europe, 3.3–3.6 and 4.8–5.0 GHz in China, and 3.5 GHz in South Korea [1,2]. Although some advancements have been accomplished (mostly in the software part and using existing 4G infrastructure) to improve the service, the transmission rates are still limited by the narrow bandwidth. In fact, when proposing 5G systems, both industries and academics agreed on the use of millimeter wave (mm-wave), i.e., with the operating frequency in the range of 24 GHz to 40 GHz [2,3] for significantly large bandwidth (large bandwidth is equivalent to large data rate). Unfortunately, the mm-wave has still not been deployed in the current 5G system. One of the main reasons is that the antenna, i.e., the end hardware part in the communication device that is used to transmit the electromagnetic signal, still does not fulfil the strict requirement of a 5G application.

The main topic articles in this issue highlight the recent advances in designing antenna systems for 5G heterogeneous networks. This Special Issue features 11 papers that present novel antenna designs synthesis along with effective approaches in order to improve the overall antenna performance. These 11 papers are concisely described as follows.

Yuxiang Tu et al. [4] give an overview and an introduction to microstrip filters, antennas, and filtering antennas (filtennas). Then, performance comparisons between the key and essential structures for these aspects are presented and discussed. Furthermore, a comparison between several RF reconfiguration techniques, current challenges, and future developments is presented and discussed in this review. Among several reconfigurable structures, the most efficient designs with the best attractive features are addressed and highlighted in this paper to improve the performance of RF and MW front-end systems.

Al-Yasir et al. [5] present a compact wide-band microstrip filter antenna design for 2.4 GHz ISM band and 4G wireless communications. The filter antenna has been designed, measured, and studied in three different dielectric substrate materials, which are Rogers RT5880, Rogers RO3003, and FR-4. The analysis was performed by using CST microwave studio software. A performance comparison for the designed filter antenna with different dielectric substrate materials and heights is presented and discussed using the same design configuration. The results obtained from each design indicate that the most suitable characteristics for a specific application can be achieved by using Rogers RT5880 dielectric substrate material. The structure is printed on a compact size of 0.32 λ0 × 0.30 λ0, where λ0 is the free-space wavelength at the center frequency. The designed filter antenna with the achieved performance can find different applications for a 2.4-GHz ISM band and 4G wireless communication.

Iqbal et al. [6] propose an isolation enhancement of two closely packed multiple-input multiple-output (MIMO) antenna systems using a modified U-shaped resonator. The modified U-shaped resonator is placed between two closely packed radiating elements resonating at 5.4 GHz with an edge to edge separation distance of 5.82 mm (λ°/10). Through careful adjustment of parametric modelling, the isolation level of −23 dB among the densely packed elements is achieved. The coupling behavior of the MIMO elements is analyzed by accurately designing the equivalent circuit model in each step. The antenna performance is realized in the presence and absence of decoupling structure, and the results show the negligible effects on the antenna performance apart from mutual coupling.

Dahri et al. [7] investigate a dual-resonance asymmetric-patch reflectarray antenna with a single layer for 5G communication at 26 GHz. The asymmetric patch is developed from a square patch by tilting its one vertical side by a carefully optimized inclination angle. A progressive phase range of 650° is acquired by embedding a circular ring slot in the ground plane of the proposed element for gain improvement. A 332-element, center-feed reflectarray is designed and tested, where its high cross polarization is suppressed by mirroring the orientation of asymmetric patches on its surface. The asymmetric-patch reflectarray offers a 3 dB gain bandwidth of 3 GHz, which is 4.6% wider than the square-patch reflectarray. A maximum measured gain of 24.4 dB was achieved with an additional feature of dual linear polarization. A simple design with a wide bandwidth and a high-gain asymmetric-patch reflectarray make it suitable for use in 5G communications at high frequencies.

Altaf et al. [8] study an antenna design for a UWB MIMO antenna system with an isolation of −20 dB. The UWB response is achieved by designing a stepped-shaped antenna while the isolation is improved by using slotted stubs etched in the ground plane within the radiating elements. The system is fabricated on an FR4 substrate. The circuit theory is used to model the circuit model and compared the results with the EM model. The simulated, measured, and the circuit model results are in good agreement. It is found that ECC and DG for the proposed system are 0.15 and 9.85 dBi, respectively. The CCL is less than 0.06 bps/Hz for the whole operating bandwidth.

Muhammad et al. [9] present a compact rectifier, capable of harvesting ambient radio frequency (RF) power. The total size of the rectifier is 45.4 mm × 7.8 mm × 1.6 mm, designed on FR-4 substrate using a single-stage voltage multiplier at 900 MHz. GSM/900 is among the favorable RF energy-harvesting (RFEH) energy sources that span over a wide range with minimal path loss and high input power. The proposed RFEH rectifier achieves measured and simulated RF-to-dc (RF to direct current) power conversion efficiency (PCE) of 43.6% and 44.3% for 0 dBm input power, respectively. Additionally, the rectifier attained 3.1-V DC output voltage across a 2-kΩ load terminal for 14 dBm and is capable of sensing low input power at −20 dBm.

Kamal et al. [10] propose and analyses a novel single-layer multiple-input multiple-output (MIMO) antenna for fifth-generation (5G) 28-GHz frequency band applications. The proposed MIMO antenna operates in the Ka-band, which is the most desirable frequency band for 5G mm-wave communication. The dielectric material is a Rogers-5880 with a relative permittivity, thickness, and loss tangent of 2.2, 0.787 mm, and 0.0009, respectively, in the proposed antenna design. The proposed MIMO configuration antenna element consists of triplet circular-shaped rings surrounded by an infinity-shaped shell. The simulated gain achieved by the proposed design is 6.1 dBi, while the measured gain is 5.5 dBi. Furthermore, the measured and simulated antenna efficiency is 90% and 92%, respectively. One of the MIMO performance metrics—i.e., the envelope correlation coefficient (ECC)—is also analyzed and found to be less than 0.16 for the entire operating bandwidth.

Bouknia et al. [11] illustrate and examine a theoretical study for the investigation of the electromagnetic field distributions and the input impedance of a printed dipole antenna structure loaded on a uniaxial anisotropic medium. The presentation of the electromagnetic field distributions, for which some examples have been shown here, provides a better understanding of the constitutive parameter (εt, εz, μt, and μz) contributions. Furthermore, the electrical and magnetic uniaxial anisotropy offers more degrees of freedom and further flexibility to realize a good direct matching effect on the input impedance. This shows that the complex media present a great potential in the design of innovative microwave components. This constitutes a starting point for understanding the behavior of the electromagnetic field in anisotropic and bianisotropic media, and many more interesting results are expected.

Addepalli et al. [12] design and implement UWB multiple-input multiple-output (MIMO) antennas with four and eight elements having connected grounds. The proposed antenna has a modified substrate geometry and comprises a circular arc-shaped conductive element on the top with the modified ground-plane geometry. Polarization diversity and isolation are achieved by replicating the elements, orthogonally forming a plus-shape antenna structure. The modified ground plane consists of an inverted L-strip and semi-ellipse slot over the partial ground that helps the antenna in achieving effective wide bandwidth spanning from (117.91%) 2.84–11 GHz. Both 4/8-port antennas help to achieve a size of 0.61 λ × 0.61 λ mm2 (lowest frequency), where the 4-port antenna is printed on the FR4 substrate. The 4-port UWB MIMO antenna attains a wide-impedance bandwidth, an omni-directional pattern, isolation of >15 dB, ECC of < 0.015, and an average gain of > 4.5 dB, making the MIMO antenna suitable for portable UWB applications.

Chung et al. [13] present an antenna structure with two branches that can achieve dual-band and broadband bandwidth characteristics. Moreover, the antenna performances were analyzed, validated, and manufactured. Thus, this design is suitable for in-vehicle infotainment and autopilot equipment systems in autonomous vehicle communication systems, including 5G, B5G, 4G, V2X, ISM band of WLAN, Bluetooth, WiFi 6 band, WiMAX, and Sirius/XM radio application.

Chung et al. [14] propose a small-slot antenna system (50 mm × 9 mm × 2.7 mm) for 4 × 4 multiple-input multiple-output (MIMO) on smart glasses devices. The antenna is set on the plastic temple, and the inverted F antenna radiates through the slot in the ground plane of the sputtered copper layer outside the temple. The antenna substrate is made of polycarbonate (PC), and its thickness is 2.7 mm (εr = 2.85, tan δ = 0.0092). The proposed antenna has a peak gain of 4.3 dBi and an antenna efficiency of 85.69% at 5.14 GHz. In addition, it also can obtain a peak gain of 3.3 dBi and antenna efficiency of 82.78% at 6.8 GHz. The measurement results show that this antenna has good performance, allowing future smart eyewear devices to be applied to Wi-Fi 5G (5.18–5.85 GHz) and Wi-Fi 6e (5.925–7.125 GHz).

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