Frontiers of Information Technology & Electronic Engineering
www.jzus.zju.edu.cn; engineering.cae.cn; www.springerlink.com
ISSN 2095-9184 (print); ISSN 2095-9230 (online)
E-mail: jzus@zju.edu.cn

Editorial:

Evolution and innovation of antenna systems for beyond 5G and 6G

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https://doi.org/10.1631/FITEE.2010000

With the advance of the 5th generation (5G) wireless communication system in recent years, 5G network construction and terminal equipment have gradually been finalized and entered the commercial stage. The 6th generation (6G) mobile communication system has become a promising and important area with both academic and industrial concerns. Compared with 5G, 6G will achieve higher access rate (10–100 times higher), lower access delay, as well as wider and deeper communication coverage, with much better energy and spectrum efficiency. It enables the material, process, technology, and forms of antenna and radio frequency (RF) systems to evolve continuously. There are several important tendencies in the development of antenna and RF systems.

1. Transform of antenna to new frequency bands

In a 5G mobile communication system, millimeter-wave (mm-Wave) band is an indispensable part. The Internet of Space (IoS), which is one of the possible evolution directions of 6G, also needs a variety of antenna systems that work in Ka and other bands to achieve wider coverage at all times and locations. In recent years, terahertz (THz) with much higher frequency has attracted wide attention from both academia and industry. It is one of the most advanced technologies recognized internationally.

2. Breakthroughs in the performance of antennas with new materials and metamaterials

New materials and metamaterials with unique features that are difficult to obtain naturally will enable antennas to be much smaller, more immune to interferences, and much better in performances. New materials and metamaterials could break the barriers for antenna theory and engineering, which were impossible with traditional materials.

3. Evolution of antenna propagation channel

New propagation characteristics are generated by antennas with a new configuration or by antennas in new frequency bands, such as three-dimensional multiple input multiple output (MIMO) antennas and mm-Wave/THz antennas. It is inevitable that antenna designers and engineers nowadays need to consider antenna performance in the presence of different channel characteristics in different scenarios and applications.

4. Significant changes in antenna-related measurement technology

In the 5G era, traditional measurement methods, indicators, and even concepts may no longer be applicable to the new 5G over the air (OTA). Brand new measurement methods and measurement indicators are being rapidly prototyped and submitted to meet international standards. At this time, it is of great importance to comprehensively make plans for 5G and 6G antenna measurement technologies.

To sum up, the antenna system for future communications is facing numerous challenges. The improvement of antenna system performance will inevitably lead to improvement of the overall performance of wireless communication systems. The evolution and innovation of antenna configurations can also pave the way for new applications.

In this context, the Chinese Academy of Engineering (CAE) organized a special issue on evolution and innovation of antenna systems for beyond 5G and 6G in *Frontiers of Information Technology & Electronic Engineering*. This special issue covers antennas, passive and active devices and systems,

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propagation and channels, as well as materials and algorithms. The available frequencies extend from sub-6 GHz all the way up to the region of THz. The special issue is intended to review the state-of-the-art antenna-related research and show future research directions. After rigorous review processes, 13 papers by researchers worldwide have been selected, including seven review articles, four research articles, and two correspondences.

Metamaterials and metasurfaces have attracted much attention due to the powerful ability in controlling electromagnetic waves. Rui-yuan WU and Tie-jun CUI summarized the fundamental knowledge of traditional metamaterials, and reviewed two-dimensional versions of metamaterials, such as spoof surface plasmon polaritons. They presented the concepts of digital coding, programmable metamaterials, and information metamaterials, as well as prospect on microwave metamaterials.

The development of metasurface antennas has provided promising solutions to wideband and low-profile antenna designs. Zhi Ning CHEN and his collaborators introduced the operating principles of typical dispersion-engineered metasurface antennas, and reviewed recent progress of such antennas. They also showed that the metasurface antenna technology is promising for innovative antenna design by discussing the functionalities of metasurface antennas.

As a continuation of 5G development, 6G has received much attention due to its high data rates, low latency, etc. Jian-hua ZHANG and her collaborators illustrated the development trends of 6G channel models by analyzing several emerging 6G technologies and applications. Based on this, perspectives of 6G channel measurements and models were described.

The MIMO technique is significant in current and future communication systems due to its advantages. Good isolation is a challenge in designing 5G terminals. Ying LIU and her collaborators analyzed the decoupling methods about 5G terminals, and provided prospects on the development trend of 5G smartphones.

To meet the demands of data transmission rate, energy-efficient power amplifiers and linearization techniques for massive MIMO transmitters have been developed. Wen-hua CHEN and his collaborators reviewed the energy-efficient integrated Doherty power amplifier monolithic microwave integrated circuits and linearization techniques for both sub-6 GHz and mm-Wave 5G massive MIMO systems. They compared different semiconductor processes and architectures, and suggested that in order to adapt to massive MIMO systems, digital pre-distortion technology needs to be improved.

With the large number of mm-Wave applications, wideband circuits and systems have attracted much attention due to their strong applicability and versatility. Yi-ming YU and Kai KANG reviewed applications in complementary metal-oxide-semiconductor (CMOS) technology from theoretical analysis and performance implementation by introducing four transformers based on ultra-wideband mm-Wave circuits, including the mm-Wave low-noise amplifier, mm-Wave injection-locked frequency tripler, mm-Wave divider, and up-conversion mixer.

Filtering antenna is a type of antenna with the integration of filtering and radiating functions. Xiu-yin ZHANG and his collaborators introduced the filtering antenna design methods and three related dual-band base-station antenna arrays. Since the filtering structure is integrated with the radiators or the feed line, no extra filtering circuit is required for filtering antennas. The inherent filtering performance of the filtering antenna can reduce mutual coupling of antennas operating in different frequency bands. Experimental results showed that some of the proposed methods can be applied to industry.

For different applications, Yuan YAO and his collaborators proposed a type of mm-Wave antenna array with flexible design in 60 GHz. The antenna array can be adjusted to be linearly or circularly polarized by changing the radiation part of the array. The antennas can obtain high gain, wide bandwidth, and high efficiency by adopting a low insertion loss feeding network and broadband antenna elements. Results showed that both linearly and circularly polarized antenna arrays have good radiation performance.

Bao-hua SUN and his collaborators presented three techniques, the Chebyshev impedance transformers, power dividers, and truncated ports with energy distribution slots, to realize miniaturization of Rotman lenses. The results indicated that it is a robust technique to miniaturize Rotman lens using the proposed truncated lens ports with energy divider slots. Moreover, the proposed miniaturized Rotman lenses can be applied to realize multi-beams and generate formed beams.

A large dual-polarization microstrip reflectarray with two operating bands was designed by Yong-chang JIAO and his collaborators. The discrete fast Fourier transform (DFFT) and inverse DFFT were used to establish a one-to-one relationship between

the aperture distribution and the far field. The intersection approach based on the alternating projection was used to obtain the desired reflection phases of all the elements at some sample frequencies in the operating bands, and a new method for producing a suitable initial solution was proposed to avoid undesired local minima. As an example, a dual-band dual-polarization microstrip reflectarray with 25 305 elements was designed to cover the continent of China. Simulation results showed that patterns of the reflectarray meet the China-coverage requirements in two operating bands, and that the proposed optimization method for designing large reflectarrays with complexly shaped patterns is reliable and efficient.

Lian-ming LI and his collaborators proposed a wideband miniaturized metasurface antenna for 60-GHz antenna-in-package applications. It was designed on a high dielectric constant glass substrate to achieve antenna miniaturization. The bandwidth performance of the antenna can be improved by supporting the TM_{10} mode and antiphase TM_{20} mode simultaneously. Good performance of the designed antenna was achieved.

A dual-module MIMO antenna for 5G portable terminals was proposed by Yong CHENG and his collaborators. The monopole and slotted antennas were staggered to improve the isolation among them. The measurement results are highly coincident with simulation results. The proposed antenna elements have wide impedance bandwidth and high efficiency, and may be a promising candidate for 5G wireless communication.

The evolution of 5G promotes innovation in antenna systems. Feng GAO and his collaborators reviewed the development of communication systems and the evolution of the requirements for antenna systems in mobile communication systems, and put forward the requirements for 5G antenna systems. As a result, weight optimization methods for massive MIMO antenna were proposed and simulated with satisfying results. The authors also provided ideas to solve the problem of power consumption of 5G antenna systems.

The papers included in this special issue cover a broad spectrum of current research topics on antennas for future communication systems, including antennas, antenna arrays, metamaterials' and natural materials' applications in antenna systems, passive and active networks and transceivers, wave propagation and channel modeling, and optimization algorithms for massive MIMO. We hope that this special issue will be beneficial to persons in wireless communication, antenna design, and related areas.

Finally, I would very much like to show my special thanks to the authors, reviewers, editors, etc. for their support and valuable contributions to this issue, such as Mr. Yong-bo LI and Ms. Ai-fen HE of the China Antenna System Industry Alliance, Profs. Ying LIU, Jian-hua ZHANG, and Wei-dong HU for the great efforts in the peer review process, the editorial staff, and the Editors-in-Chief, Profs. Yun-he PAN and Xi-cheng LU.

Prof. Bao-yan DUAN, an academician of the Chinese Academy of Engineering, received BS, MS, and PhD degrees in Electromechanical Engineering from Xidian University, Xi'an, China, in 1981, 1984, and 1989, respectively. He was a postdoctoral fellow at Liverpool University, UK from 1991 to 1994 and a visiting scientist at Cornell University, Ithaca, NY, USA in 2000. He is currently a full professor at the School of Electromechanical Engineering of Xidian University, where he founded the research institute on mechatronics about electronic equipment structural design.

He is the chairman of the China Antenna System Industry Alliance, and chairman of the Electromechanical Engineering Society of China. He is a fellow of the Institution of Engineering and Technology and of the Chinese Institute of Electronics. He serves as the chief editor of *Electromech Eng China*, deputy chief editor of *Chin J Electron*, subject chief editor of *Engineering*, and editor of more than 10 other journals.

He has been dedicating himself to research of electromechanical engineering and opened new area of electromechanical coupling (EMC) theory of microwave electronic equipment (MEE) in China. He has established the multifield coupling theory model (MFCTM) among electromagnetic, structural deformation, and temperature fields of MEE, made known the influence mechanism (IM) of nonlinear mechanical parameters on electronic performance of MEE, and developed the integrated design methodology of MEE based on MFCTM and IM. The above results have been successfully applied in national major engineering projects, such as lunar exploration, Shenzhou spacecraft, "Tiantong No. 1," and the Five-hundred-meter Aperture Spherical radio Telescope (FAST).

He has authored or coauthored 200 papers and six books, and obtained 40 patents of invention. He has received, as the first author, the second prize of the National Award for Science and Technology Progress of China three times in 2004, 2008, and 2013. In 2012, he was awarded the Hong Kong HLHL Prize for Science and Technology Progress. In 2017, he received award for outstanding scientific and technological achievement from the Chinese Academy of Sciences and the Golden Prize of China Good Design. In 2018, he received the life achievement award from the Asian Society of Structural and Multidisciplinary Optimization.

China Central Television (CCTV) made and broadcasted a special program, entitled "DUAN Bao-yan: Minor Discipline and Great Vision" in 2016 (http://eesd.xidian.edu.cn).