The Importance of the New Developments in Antennas for Wireless Communications

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The antenna was born when the existence of electromagnetic waves was first demonstrated by Heinrich Hertz over 113 years ago. Since then, many simple but efficient antennas were invented to support the growth of radio-frequency (RF) technology. When optical fiber communications was growing at a rapid pace in the 1980s, the efforts for further development of antenna and microwave innovations was discouraged. The success in the advancement of the second-generation (2G) mobile phone in the early 1990s changed the entire landscape of the telecommunication industry. Many new RF communication standards, under the umbrella of "wireless communications," have been proposed and developed over the last two decades. It is an ultimate goal of all wireless communication engineers to build a wireless world.

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I. CHALLENGING ISSUES

An antenna is a necessary component of any wireless system. In contrast to the classical dish-like reflector antennas that stand out as giants in a plain field and the fishbone-like Yagi antennas that once colonized the rooftops of high-rise buildings in many cities, most of the antennas for modern wireless communications are required to be small in size or low in profile. This requirement enables them to be embedded easily into mounting bodies for enhancing portability or maintaining aerodynamic performance. As these antennas are not conspicuous, their existence is easily ignored by the general public. Recently, when people experienced the "death grip" of the iPhone4, they recognized the importance of antenna design in wireless communications. Antennas therefore are no longer a silent partner in this revolution of personal communications.

Most antennas for modern wireless communications are complex in structure, with irregular metal patches and finite dielectric substrates. Their characteristics can also be affected by the geometries of mounting devices. Analysis of these antennas must be relied on sophisticated numerical approaches including integral equation techniques and finite-difference–time-domain methods. Efficient optimization techniques such as genetic algorithms and particle swarm processes may be employed to generate accurate design solutions. Many commercial design tools are now available to simplify the lives of practicing antenna engineers.

A conventional RF communication system has one antenna in the transmitter and another antenna in the receiver, commonly designated as a single-input–single-output (SISO) system. In the last decade, significant advances in the multiple-input–multiple-output (MIMO) technology have been achieved by wireless communication engineers. This is due to the development of spatial multiplexing and diversity coding techniques to increase the channel capacity of MIMO systems. It is apparent that MIMO will be employed in many released and to be released in the future wireless communication standards. Advanced diversity antennas are required to support this exciting new development. Conventional antennas with a single input port can be tested in a far-field range, compact range, or near-field measurement systems. For measurement of the throughput of a MIMO system, a reverberation chamber may be employed. The reverberation chamber is very efficient for the characterization of diversity antennas for MIMO systems.

The success in wireless communications has given fresh impetus to the continuous development of generic resonant antennas, including wire antennas, slot antennas, microstrip patch antennas, and dielectric resonator antennas. Major design efforts have been focused on bandwidth enhancement, multiband operation, size reduction, and the shaping of the radiation pattern. These antennas serve as references for practical designs in various wireless systems. Much work has also been done on planar nonresonant leaky-wave antennas which have the attractiveness of structural simplicity, simple feeding structure, easy fabrication, and high directivity. They are suitable for various scanning applications, including MIMO and radar systems. They are also attractive for millimeter-wave systems.

II. INNOVATIVE ANTENNA TECHNOLOGIES

The rapid pace in the development of various wireless communication systems is partially attributed to the contemplation of innovative antenna technologies including diversity antennas, reconfigurable antennas, metamaterial-based antennas, and antennas for software-defined radio. Diversity antennas are multiple-antenna systems which can improve the quality and reliability of a wireless link through a spatial, polarization, or pattern diversity scheme.

Reconfigurable antennas can offer new capabilities for future wireless applications. By incorporating PIN diodes (diodes with a wide intrinsic semiconductor layer between the P and N layers) or microelectromechanical system (MEMS) switches into the topology of an antenna, the radiation characteristics of such antennas including frequency response, radiation patterns, gain, or a combination of several radiation parameters can be adapted with changing system requirements or environmental conditions.

Metamaterials are artificial composite materials designed to have a negative value of reflective index. Antennas with metamaterials can refract electromagnetic waves more than conventional antennas, which results in antenna size reduction without reducing too much their frequency bandwidth. Using metamaterials, a cellular phone may be able to concentrate the radiating current closer to the antenna structure, which reduces the user's hand and head intervention on the antenna performance.

A software-defined radio system which has all the traditional components—mixer, filter, amplifier, modulators/demodulator, and detector—implemented by software means can tune across a wide frequency spectrum and receive or transmit any kind of modulated signals. With the rapidly evolving capabilities of digital electronics, the software-defined radio is expected to become the dominant RF communication technology, which needs sophisticated broadband antennas with tunable capability.

III. VARIOUS WIRELESS APPLICAIONS

The variety of existing or future wireless communication networks is growing and includes digital cellular networks, wireless sensor networks, wireless networking for internet access, short-range point-to-point wireless connectivity, mobile broadcasting systems, global navigation satellite systems, body-centric wireless communication systems, millimeter-wave personal area networks, millimeter-wave automotive sensors, and terahertz biosensor and surveillance systems. These networks require different types of radiating elements with different characteristics. It is a challenging task to design antennas fulfilling those stringent requirements imposed by individual communication networks.

In cellular mobile networks, different requirements are imposed on the characteristics of antennas for mobile communication devices and base stations. For handsets and notebook computers, we need embedded antennas with small size and wide operating frequency bands, which is a challenging task as the two requirements are usually in conflict, governed by physical bounds. For base stations, we need panel antennas with wide bandwidth, low cross-polarization, low back radiation, upper sidelobe suppression, no nulls in the serving area, and high isolation in dual-polarized designs.

In wireless networking for internet access, such as Wi-Fi connectivity, the challenges in the design of antennas for Wi-Fi enabled devices are different from that for the access points. Antennas for mobile devices have critical constraints on cost and size, which limit the antenna performance. Antennas for access points and routers face the demands for high performance, low costs, and integration of multiple functions into a single-antenna system.

For enabling short-range high data rate wireless connectivity, the unlicensed ultrawideband (UWB) system was introduced for providing an efficient use of limited RF bandwidth. In general, UWB systems require sophisticated broadband small antennas that can be operated from 3.1 to 10.6 GHz with stable phase centers.

A wireless sensor network can be implemented with state-of-the-art radio-frequency identification (RFID) technologies. One hot topic for these technologies is on the design of the chipless RFID tag. Without the use of silicon chips, the demand for a tag costing 0.1 cents and printable directly on an item will be achieved very soon. These tags require transmitting and receiving antennas with small sizes and high isolation between the two antennas.

The incorporation of digital television service in handheld devices, such as the digital video broadcast-handheld (DVB-H) operated at UHF band from 470 to 862 MHz poses a challenging problem for antenna designers. We need very wideband small antennas or electrically tunable narrowband small antenna to fulfill the requirement.

The success of the global positioning system (GPS) fosters the development of global navigation satellite systems by other countries, including systems such as Galileo, GLONASS, and COMPASS. The common requirements for the circularly polarized receiving antennas of these systems are small size and wide beamwidth. In high precision applications, very symmetrical radiation patterns with low backlobes are needed. Broadband circularly polarized antennas covering all the existing systems are also welcome in practice.

Investigation on body-centric communications has become a promising area of research owing to their various potential applications in e-healthcare, supporting systems for specialized occupations, monitoring systems for elderly and handicapped people, entertainment, etc. In general, these systems require miniature wearable or implantable antennas.

The approval of about 7 GHz of unlicensed bandwidth in the 60-GHz band for wireless personal area networks has fostered numerous research collaborative activities worldwide. With the advances in standard complementary metal–oxide–semiconductor (CMOS) technology for millimeter-wave integrated circuits, the 60-GHz systems have become commercially viable for low-cost, high data rate, short-range wireless communications with reliable performance. Integrated antenna arrays with scanning capability are demanded for these systems.

Collision avoidance millimeter-wave radar systems have emerged as an important sensor for vehicle safety. This is due to their high resolution, high reliability, compactness, and low fabrication and integration costs. Novel designs of low-cost high-gain antenna arrays are required for automotive radars which are operated at 77 GHz.

The terahertz frequency technology is a promising technology which has potential applications in many areas, including biosensors, material measurements, and broadband communications. In particular, it can be used to detect hidden explosives, illegal drugs, and biological and chemical agents remotely. With the availability of terahertz testing equipment and nanofabrication facilities, this area of technology has received much attention in recent years. For these systems, the antennas and circuits cannot be separated. Efficient on-chip antennas are demanded to support the development of this exciting new technology.

IV. CONCLUSION

To conclude, with the blooming of modern wireless communication technologies, antenna research is entering another phase of significant development. In general, a wireless communication antenna is required to be available to cover a wide frequency bandwidth or several frequency bands. It is expected to be small in size or low in profile. It is no longer an isolated element and should be integrated with other circuit components. To achieve high performance, it must be codesigned with its mounting body and if possible with its environment.

We are very pleased to note that a special issue that will discuss the technical design details of antennas in wireless communications is scheduled to be published by the Journal in 2012. ■