The Scanning the Literature column provides concise summaries of selected papers that have recently been published in the field of networking. Each summary describes the paper's main idea, methodology, and technical contributions. The purpose of the column is to bring the state of the art of networking research to readers of *IEEE Network*. Authors are also welcome to recommend their recently published work to the column, and papers with novel ideas, solid work, and significant contributions to the field are especially appreciated. Authors wishing to have their papers presented in the column should contact the Editor.

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Metamaterials are artificially engineered materials with electromagnetic (EM) properties that are not owned by natural materials, which could be composed of subwavelength-scale meta-particles arranged periodically or quasi-periodically. How to utilize such materials to enhance capabilities of communication has become an interesting issue attracting attention from both the science and engineering communities. The column in this issue focuses on recent research on electromagnetic metamaterials, in particular, Chiral Metamaterials, leaky-wave antennas, and digital coding and programmable metasurfaces.

For readers with no background knowledge, the following survey paper is recommended.

Microwave Metamaterials: From Exotic Physics to Novel Information Systems

R. Wu, T. Cui, "Microwave metamaterials: from exotic physics to novel information systems," *Frontiers of Information Technology & Electronic Engineering*, vol. 21, no. 1, pp. 4-26, 2020.

In this paper, the authors review the recent developments in the field of EM metamaterials, starting from their exotic physics to their applications in novel information systems. First, they show the fundamental understanding on traditional metamaterials based on the effective medium theory and related applications, such as invisibility cloaks and meta-lenses. Second, they review the two-dimensional versions of metamaterials, i.e., metasurfaces, for controlling spatial waves and surface waves and thereafter present their typical designs. In particular, the authors briefly introduce spoof surface plasmon polaritons and their applications in microwave frequencies. Following the above approach, they emphatically present the concepts of digital coding metamaterials, programmable metamaterials, and information metamaterials. By extending the principles of information science to metamaterial designs, several functional devices and information systems are presented, which enable digital and EM-wave manipulations simultaneously. Finally, they give a brief summary of the development prospects for microwave metamaterials.

Chiral Metamaterials (CMMs) are artificial materials having no plane of mirror symmetry and have strong ability to rotate the plane of polarization of electromagnetic waves. There are some attractive methods in the literature for retrieval of electromagnetic properties of an individual reciprocal CMM slab, which, however, are inapplicable not only because they are feasible for electromagnetic properties of one individual CMM slab only, but also because they do not consider the coupling effect between resonating MM slabs in close proximity. To solve these challenges, U. C. Hasar and M. Bute propose an extraction algorithm in the following paper.

Method for Retrieval of Electromagnetic Properties of Inhomogeneous Reciprocal Chiral Metamaterials

U. C. Hasar, M. Bute, "Method for Retrieval of Electromagnetic Properties of Inhomogeneous Reciprocal Chiral Metamaterials," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 7, pp. 5714-5717, 2020.

The authors have proposed an extraction algorithm which takes into account of coupling phenomenon for determining electromagnetic properties of inhomogeneous reciprocal chiral metamaterials (CMMs). They first obtained recursive reflection and transmission coefficients for right-hand and left-hand circularly polarized plane waves and then derived the expressions of refractive indices, wave impedance, and chirality parameter of a CMM slab using these recursive coefficients. They examined a three-layer inhomogeneous CMM structure composed of U-shape and crescent-shape metamaterial (MM) slabs and retrieved electromagnetic properties of U-shaped CMM slab. Finally, they considered the effect of noise added into transmission coefficient to evaluate the robustness of their method against noise.

Wireless power transfer (WPT) systems via magnetic resonance coupling (WPT/MRC) have attracted extensive attention since WPT technology has great advantages of portability and security. However, there are some bottlenecks that need to be broken through. For example, the power transfer efficiency will be sharply reduced as the transfer distance increases. In addition, the leakage electromagnetic field (EMF) from WPT systems is another troublesome issue. To address these issues, C. Lu *et al*. introduce their solutions in the following paper:

Investigation of Negative and Near-zero Permeability Metamaterials for Increased Efficiency and Reduced Electromagnetic Field Leakage in a Wireless Power Transfer System

C. Lu, C. Rong, X. Huang , Z. Hu, X. Tao, S. Wang , J. Chen, M. Liu, "Investigation of negative and near-zero permeability metamaterials for increased efficiency and reduced electromagnetic field leakage in a wireless power transfer system," *IEEE Transactions on Electromagnetic Compatibility*, vol. 61, no. 5, pp. 1438-1446, 2018.

In order to meet both safety and efficiency requirements of wireless power transfer (WPT) systems, reducing electromagnetic field (EMF) leakage and improving efficiency are critical factors in the implementation of systems. Recently, metamaterials have exhibited the ability to control electromagnetic wave propagation. In this paper, the WPT system integrating with near-field mu-near-zero (NF-MNZ) and mu-negative permeability (MNG) metamaterials is proposed to control EMF leakage below a certain level and improve transfer efficiency. The NF-MNZ and the MNG metamaterials are placed on both sides and in the middle of the WPT system, respectively. In addition, the property of the NF-MNZ metamaterial slab and its working principle on the WPT system are analyzed. The shielding performance of the NF-MNZ metamaterial are evaluated via numerical simulation and experimental investigation. Finally, the efficiency and the magnetic field strength of the WPT system with two different types of metamaterials have been investigated by the experimental measurements. At the transfer distance of 40 cm, the experimental results show that the efficiency of the WPT system is increased by 12.06% and the magnetic field strength is reduced by 62.09%.

Leaky-wave antennas (LWAs) have been extensively used because of their unique advantages of low profile, high gain, and frequency-scanning characteristics. Much effort has been made to realize fixed-frequency beam-scanning LWAs, but most of them can only work in a single frequency band. To develop the dual-band LWAs to satisfy the multiplexing requirement, in the following paper C. Lu *et al*. propose a dual-band fixed-frequency beam-scanning leaky-wave antenna (LWA) based on a corrugated microstrip line (CML).

A Dual-Band Electronic-Scanning Leaky-Wave Antenna Based on a Corrugated Microstrip Line

C. Lu, C. Rong, X. Huang, Z. Hu, X. Tao, S. Wang, J. Chen, M. Liu, "A dual-band electronic-scanning leaky-wave antenna based on a corrugated microstrip line," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 5, pp. 3433-3438, 2019.

A dual-band fixed-frequency beam-scanning leaky-wave antenna (LWA) based on a corrugated microstrip line (CML) has been proposed. The proposed CML includes a series of uniform grooves that are alternately loaded by capacitors and varactors. The unit cell of the CML supports two kinds of modes in two different frequency bands. In each band, the dispersion characteristics of the CML can be electronically tuned by changing the capacitance loaded in the unit cell. Therefore, by simply changing the bias voltage of the loaded varactor diodes in the CML, the surface impedance of the LWA is dynamically reconfigured, and moreover, the radiation beams of the LWA are electronically steerable at a fixed frequency in each band. The experimental results show that at 4.25 and 5.75 GHz, the designed dual-band LWA can electronically steer the radiation beams in the maximum range of 80° and 22°, respectively, by changing the bias voltage from 0 to 10V.

Metasurfaces have been widely used to manipulate electromagnetic (EM) waves in unconventional ways. As the digital version of metasurface, digital coding and programmable metasurfaces have rapidly developed. So far, 1-bit and 2-bit programmable metasurfaces have been successfully realized by using active devices and field-programmable gate array (FPGA). Since higher bit programmable metasurfaces have lower quantization phase error and can control EM waves more precisely and have stronger capability to manipulate EM waves, L. Zhang *et al*. propose to realize arbitrary multi-bit programmable phases in the following paper.

Dynamically Realizing Arbitrary Multi-Bit Programmable Phases Using a 2-Bit Time-Domain Coding Metasurface

L. Zhang, Z. X. Wang, R. W. Shao, J. L. Shen, X. Q. Chen, X. Wan, Q. Cheng, T. J. Cui, "Dynamically realizing arbitrary multi-bit programmable phases using a 2-bit time-domain coding metasurface," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 4, pp. 2984-2992, 2019.

Recently, digital coding metasurfaces have attracted significant attention due to their capability to dynamically control electromagnetic waves in programmable ways. When the digital bit of a metasurface is higher, its controlling capability will be stronger. However, it is extremely difficult to realize 3-bit and higher digital coding metasurfaces since an *n*-bit digital element will require many active devices (e.g., p-i-n diodes) to achieve 2*n* digital states. Here, the authors propose to realize arbitrary multi-bit programmable phases using 2-bit time-domain digital coding metasurface at the central frequency or harmonic frequencies. They introduce the method of vector synthesis to design the phase coverages, from which 4-bit and arbitrarily higher-bit coding phases are synthesized by a physical coding metasurface with only 2-bit phases, simply by manipulating the time-coding sequences. A prototype controlled by a field-programmable gate array is used to validate this methodology. The experimental results are in good agreement with the theoretical analysis, which demonstrate good performance of the proposed method in dynamically realizing arbitrary multi-bit programmable phases. This time-varying coding strategy provides a new way to design higher bit programmable metasurface and simplify the structural design and control system, which will find many potential applications such as high-resolution imaging and high-capacity wireless communications.

Looking forward to future wireless communication technologies for sixth-generation (6G) mobile communication, one possibility is to further scale up in terms of the number of antennas and/ or frequency band to meet the ever-increasing traffic demands. Among the various new technologies, the introduction of extremely large aperture antenna arrays like ultra-massive MIMO (UM-MIMO) and the use of the terahertz (THz) band are regarded as the most promising approaches. However, due to the extremely large number of radio frequency (RF) chains required by UM-MIMO and the high complexity in the design and manufacture of the high-performance RF components working in high frequency bands, UM-MIMO and THz technologies suffer from the extremely high hardware cost for practical implementation. To address these new challenges, in the following paper W. Tang *et al*. propose the wireless communication enabled by programmable metasurfaces.

Wireless Communications with Programmable Metasurface: New Paradigms, Opportunities, and Challenges on Transceiver Design

W. Tang, M. Z. Chen, J. Y. Dai, Y. Zeng, X. Zhao, S. Jin, Q. Cheng, T. J. Cui, "Wireless communications with programmable metasurface: New paradigms, opportunities, and challenges on transceiver design," *IEEE Wireless Communications*, vol. 27, no. 2, pp. 180-187, 2020.

Various emerging technologies, such as UM-MIMO and THz communications are under active discussion as promising technologies to support the extremely high access rate and superior network capacity in the future 6G mobile communication systems. However, such technologies are still facing many challenges for practical implementation. In particular, UM-MIMO and THz communication require an extremely large number of RF chains, and hence suffer from prohibitive hardware cost and complexity. In this article, the authors introduce the emerging paradigm called wireless communication enabled by programmable metasurfaces to address the above issues, by exploiting the powerful capability of metasurfaces in manipulating electromagnetic waves. They will first introduce the basic concept of programmable metasurfaces, followed by the promising paradigm shift in future wireless communication systems enabled by programmable metasurfaces. In particular, the authors give an overview of the two prospective paradigms of applying programmable metasurfaces in wireless transceivers, namely, RF chain-free transmitter and space-down-conversion receiver, which both have great potential to simplify the architecture and reduce the hardware cost of future wireless transceivers. Furthermore, they present the design architectures, preliminary experimental results and main advantages of these new paradigms and discuss their potential opportunities and challenges toward ultra-massive 6G communications with low hardware complexity, low cost, and high energy efficiency.