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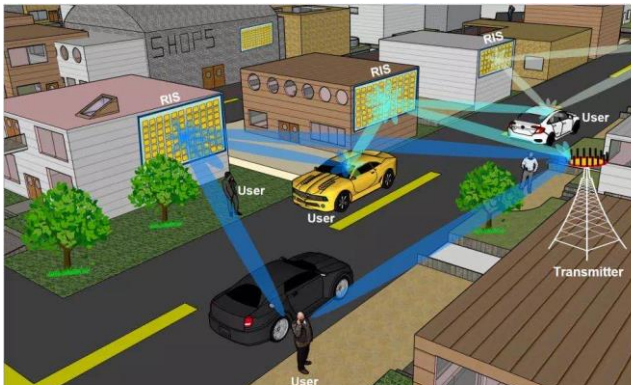
编者按：从 1G 到 5G，无线信道通常被认为是无线通信系统中不可调控的部分。近年来，随着超材料技术的快速发展，智能超表面技术（Reconfigurable Intelligent Surface，RIS）因其具有调控无线信道的能力，为通信系统的设计提供了一种新的范式，是未来 6G 中颇有前景的关键技术之一。

本期学术快报聚焦智能超表面技术，介绍相关论文、会议、期刊主题征文等内容。



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2021-第 13 期-智能超表面技术

智能超表面（RIS）实践

智能超表面（Reconfigurable Intelligent Surface,RIS）是一种具有可编程电磁特性的人工电磁表面结构，由超材料技术发展而来。RIS 技术能够突破传统无线信道不可控特性，实现主动地控制无线传播环境，在三维空间中实现信号传播方向调控及增强或消除，抑制干扰并增强信号，构建智能可编程无线环境新范式。作为一种极具潜力的基础性关键技术，RIS 具有低成本、低功耗、易部署等特点，将能够支持绿色通信，智能无线环境。RIS 通过构建智能中控无线环境，将有机会增强 5G-Adv 网络，并为 6G 带来一种全新的通信网络范式。

2021 年 7 月，中国移动联合东南大学崔铁军院士团队、杭州钱塘信息有限公司，率先在南京现网完成电磁单元器件可调、波束方向可灵活控制的智能超表面技术验证。初步测试结果表明，智能超表面可根据用户分布，灵活地调整无线环境中的信号波束，显著改善现网弱覆盖区域的信号强度、网络容量和用户速率。在室外测试场景下，小区边缘覆盖平均提升 3~4 dB，边缘用户吞吐量提升约 10 倍以上；在室外覆盖室内测试场景下，室内覆盖提升约 10 dB，用户吞吐量提升至 2 倍左右。

图 1 智能超表面典型应用场景示意图

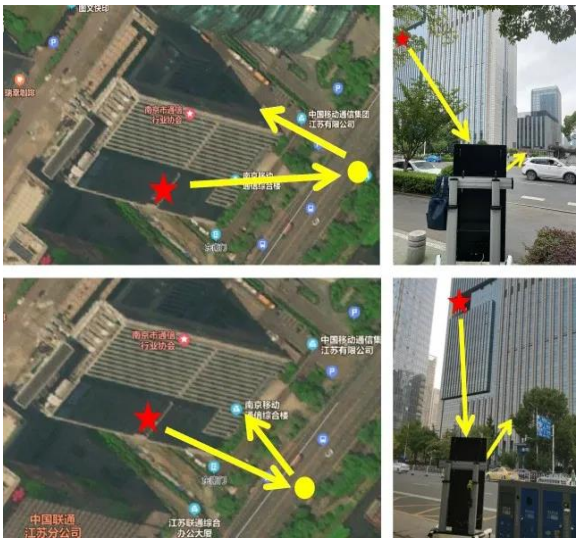

图 2 智能超表面测试现场

针对技术及产业成熟度相对较高的智能反射面，中国移动结合网络运营经验提出了三阶段的发展思路。第一阶段实现无源静态反射面，可快速部署并满足弱覆盖场景中扩展网络覆盖和补盲的需求；第二阶段实现半静态可控反射面，通过器件单元调控实现波束选择，扩展超表面波束覆盖范围、提升小区容量和速率；第三阶段实现动态智能反射面，通过编码算法动态跟踪用户位置、匹配信道环境，从而实现 6G 的电磁波传播智能调控。

智能超表面（RIS）论文

东南大学崔铁军院士是信息超材料领域的创始人，从 2004 年开始研究电磁超材料，在超材料的创新机理、理论和方法上实现了业内领先。2014 年，崔铁军院士团队业界率先实现了智能超表面的硬件系统，在智能超表面方面积累了丰硕成果。

2021 年 7 月 29 日发表在国际知名期刊《国家科学评论》（National Science Review）上的“基于时域数字编码超表面的宽带精确电磁谐波幅相调控与 256QAM 毫米波无线通信（ Accurate and broadband manipulations of harmonic amplitudes and phases to reach 256 QAM millimeter-wave wireless communications by time-domain digital coding metasurface ）”是崔铁军院士（崔铁军院士为通讯作者，另有程强教授和金石教授为共同通讯作者）关于智能超表面的最新研究成果。该成果基于时域数字编码超表面提出了一种全新的编码方法，能够在超宽的频带范围内实现对电磁谐波幅度和相位的精确调控。在此基础上，进一步提出并实际搭建了调制体制为 256 QAM 的高阶毫米波无线通信系统。新系统相较于传统的毫米波无线通信系统架构更为简单，因而极大地降低了硬件成本。

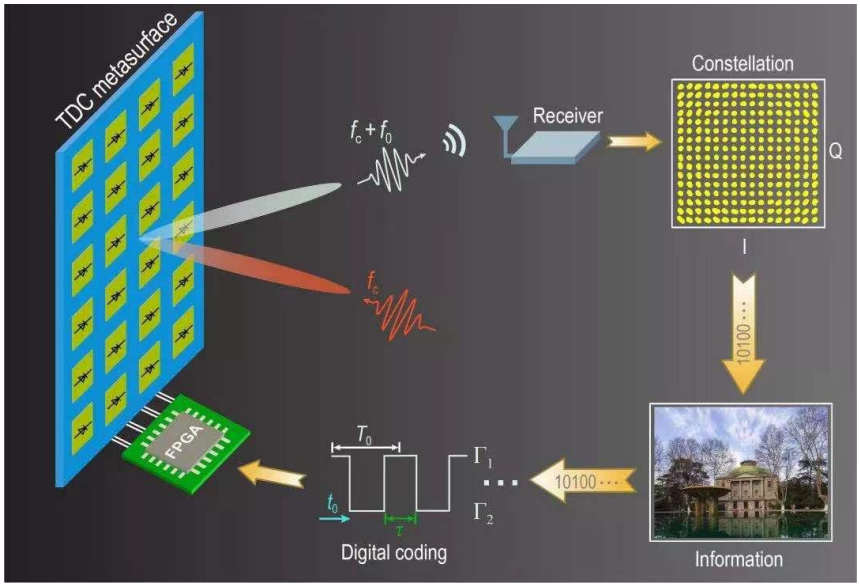

图 3 基于时域数字编码超表面的毫米波无线通信系统示意图

题名： Accurate and broadband manipulations of harmonic amplitudes and phases to reach 256QAM millimeter-wave wireless communications by time-domain digital coding metasurface
出版信息： National Science Review, https://doi.org/10.1093/nsr/nwab134，29 July 2021
作者： Ming Zheng Chen, Wankai Tang, Jun Yan Dai, Jun Chen Ke, Lei Zhang, Cheng Zhang, Jin Yang, Lianlin Li, Qiang Cheng, Shi Jin, Tie Jun Cui
原文链接： https://academic.oup.com/nsr/advance-article/doi/10.1093/nsr/nwab134/6330461
Abstract： We propose a theoretical mechanism and new coding strategy to realize extremely accurate manipulations of nonlinear electromagnetic harmonics in ultrawide frequency band based on a time-domain digital coding metasurface (TDCM). Using the proposed mechanism and coding strategy, we design and fabricate a millimeter-wave (mmWave) TDCM, which is composed of reprogrammable meta-atoms embedded with PIN diodes. By controlling the duty ratios and time delays of the digital coding sequences loaded on TDCM, experimental results show that both amplitudes and phases of different harmonics can be

engineered at will simultaneously and precisely in broad frequency band from 22 to 33 GHz, even when the coding states are imperfect, which have good agreements with theoretical calculations. Based on the fabricated high-performance TDCM, we further propose and experimentally realize a large-capacity mmWave wireless communication system, where 256 quadrature amplitude modulation (QAM) along with other schemes are demonstrated. The new wireless communication system has a much simpler architecture than the currently used mmWave wireless systems, and hence can significantly reduce the hardware cost. We believe that the proposed method and system architecture can find vast applications in the future mmWave and terahertz-wave (THzWave) wireless communication and radar systems.

延伸阅读：

[1] An optically driven digital metasurface for programming electromagnetic functions

出版信息： Nature Electronics volume 3, pages165–171 (2020)

作者： Xin Ge Zhang, Wei Xiang Jiang, Hao Lin Jiang, Qiang Wang, Han Wei Tian, Lin Bai, Zhang Jie Luo, Shang Sun, Yu Luo, Cheng-Wei Qiu & Tie Jun Cui

原文链接： https://www.nature.com/articles/s41928-020-0380-5

Abstract： Metasurfaces are engineered surfaces that consist of subwavelength periodic elements and can be used to manipulate electromagnetic waves. Multifunctional or reconfigurable electromagnetic meta-devices based on a direct-current biasing system can be built using lumped electronic components. However, such meta-devices require bulky power supplies, field-programmable gate arrays, electrical wires and complex control circuits. Here, we report a digital metasurface platform that can be programmed optically to implement electromagnetic functions. Our digital platform has 6 × 6 subarrays, each of which contains 4 × 4 metasurface elements based on electronic varactors integrated with an optical interrogation network based on photodiodes. The interrogation network can convert visible light illumination patterns to voltages and applies bias to the metasurface elements, generating specific microwave reflection phase distributions. To illustrate the capabilities of our approach, we use the optically driven digital metasurface for external cloaking, illusion and dynamic vortex beam generation.

[2] Space-time-coding digital metasurfaces

出版信息： Nature Communications,volume 9,2018

作者: Zhang, L ; Chen, XQ ; Liu, S; Zhang, Q ; Zhao, J ; Dai, JY ; Bai, GD ; Wan, X ; Cheng, Q ; Castaldi, ; Galdi, V; Cui, TJ

原文链接： https://www.nature.com/articles/s41467-018-06802-0

Abstract： The recently proposed digital coding metasurfaces make it possible to control electromagnetic (EM) waves in real time, and allow the implementation of many different functionalities in a programmable way. However, current configurations are only space-encoded, and do not exploit the temporal dimension. Here, we propose a general theory of space-time modulated digital coding metasurfaces to obtain simultaneous manipulations of EM waves in both space and frequency domains, i.e., to control the propagation direction and harmonic power distribution simultaneously. As proof-of-principle application examples, we consider harmonic beam steering, beam shaping, and scattering-signature control. For validation, we realize a prototype controlled by a field-programmable gate array, which implements the harmonic beam steering via an optimized space-time coding sequence. Numerical and experimental results, in good agreement, demonstrate good performance of the proposed approach, with potential applications to diverse fields such as wireless communications, cognitive radars, adaptive beamforming, holographic imaging.

[3] Compact User-Side Reconfigurable Intelligent Surfaces for Uplink Transmission
出版信息：arXiv preprint arXiv:2107.08698, Jul. 2021
作者: Kunzan Liu, Zijian Zhang, Linglong Dai, Lajos Hanzo
原文链接：https://arxiv.org/abs/2107.08698
Abstract：Large-scale antenna arrays employed by the base station (BS) constitute an essential next-generation communications technique. However, due to the constraints of size, cost, and power consumption, it is usually considered unrealistic to use a large-scale antenna array at the user side. Inspired by the emerging technique of reconfigurable intelligent surfaces (RIS), we firstly propose the concept of user-side RIS (US-RIS) for facilitating the employment of a large-scale antenna array at the user side in a cost- and energy-efficient way. In contrast to the existing employments of RIS, which belong to the family of base-station-side RISs (BSS-RISs), the US-RIS concept by definition facilitates the employment of RIS at the user side for the first time. This is achieved by conceiving a multi-layer structure to realize a compact form-factor. Furthermore, our theoretical results demonstrate that, in contrast to the existing single-layer structure, where only the phase of the signal reflected from RIS can be adjusted, the amplitude of the signal penetrating multi-layer US-RIS can also be partially controlled, which brings about a new degree of freedom (DoF) for beamformer design that can be beneficially exploited for performance enhancement. In addition, based on the proposed multi-layer US-RIS, we formulate the signal-to-noise ratio (SNR) maximization problem of US-RIS-aided communications. Due to the non-convexity of the problem introduced by this multi-layer structure, we propose a multi-layer transmit beamformer design relying on an iterative algorithm for finding the optimal solution by alternately updating each variable. Finally, our simulation results verify the superiority of the proposed multi-layer US-RIS as a compact realization of a large-scale antenna array at the user side for uplink transmission.

[4]RIS-Aided Wireless Communications: Prototyping, Adaptive Beamforming, and Indoor/Outdoor Field Trials
出版信息：arXiv preprint arXiv: 2103.00534, Feb. 2021
作者：Xilong Pei, Haifan Yin, Li Tan, Lin Cao, Zhanpeng Li, Kai Wang, Kun Zhang, Emil Björnson
原文链接：https://arxiv.org/abs/2103.00534
Abstract：The prospects of using a Reconfigurable Intelligent Surface (RIS) to aid wireless communication systems have recently received much attention from academia and industry. Most papers make theoretical studies based on elementary models, while the prototyping of RIS-aided wireless communication and real-world field trials are scarce. In this paper, we describe a new RIS prototype consisting of 1100 controllable elements working at 5.8 GHz band. We propose an efficient algorithm for configuring the RIS over the air by exploiting the geometrical array properties and a practical receiver-RIS feedback link. In our indoor test, where the transmitter and receiver are separated by a 30 cm thick concrete wall, our RIS prototype provides a 26 dB power gain compared to the baseline case where the RIS is replaced by a copper plate. A 27 dB power gain was observed in the short-distance outdoor measurement. We also carried out long-distance measurements and successfully transmitted a 32 Mbps data stream over 500 m. A 1080p video was live-streamed and it only played smoothly when the RIS was utilized. The power consumption of the RIS is around 1 W. Our paper is vivid proof that the RIS is a very promising technology for future wireless communications.

智能超表面技术论坛
RIS TECH FORUM

第一届智能超表面（RIS）技术论坛

受 7 月南京突发新型冠状病毒肺炎疫情影响，原定于 2021 年 7 月 23 日在南京金陵饭店召开的第一届智能超表面（RIS）技术论坛延期举行（暂定 2021 年 9 月 3 日，北京）。

会议主题：使能智能无线环境，重构未来移动通信网络

会议形式与内容：PART I：特邀报告（国内外专家学者，现场&线上）

PART II：圆桌会议

PART III：RIS Demo 展示（实物&视频）

特邀嘉宾：邬江兴 中国工程院院士

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马红兵 中国联通科技创新部 总经理

向际鹰 中兴通讯首席科学家

详细信息请戳：
http://dt04.vtc365.cn:8080/LiveVideoServer/ris/index.html

智能超表面（RIS）主题征文

《电子与信息学报》

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RIS 征文主题：

- 智能超表面通信网络基础理论与性能极限
- 智能超表面网络信道建模与信道估计
- 智能超表面辅助的感知通信一体化
- 智能超表面辅助的密集异构网络
- 智能超表面辅助的中继通信
- 智能超表面选择与资源分配
- 基于能量收集的智能超表面通信
- 智能超表面数能同传理论
- 智能超表面通信网络性能分析
- 基于移动边缘计算的智能超表面通信技术
- 智能超表面通信网络 AI 使能技术
- 基于全双工的智能超表面通信技术
- 智能超表面通信系统架构与验证平台

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http://jeit.ie.ac.cn/news/bianjibugonggao/6d265efa-d028-408c-90a7-87d6b8f640d8.htm

智能超表面（RIS）视频资源

RIS 前沿技术系列讲座(一)：面向 6G 的信息超材料无线通信
主讲人： 金石 教授 (东南大学)
https://www.bilibili.com/video/BV1t54y1v7TR/?spm_id_from=333.788.b_7265636f5f6c697374.5
RIS 前沿技术系列讲座(二)：信息超材料：机遇与挑战
主讲人： 程强 教授 (东南大学)
https://www.bilibili.com/video/BV1kz4y1f7B3/?spm_id_from=333.788.videocard.3
RIS 前沿技术系列讲座(三)： 面向 6G 通信的智能反射面 (IRS) 技术
主讲人： 武庆庆 助理教授 (澳门大学)
https://www.bilibili.com/video/BV1wZ4y1N7J4/?spm_id_from=333.788.b_7265636f5f6c697374.8
RIS 前沿技术系列讲座(四)：Modeling and Optimizing Realistic Reconfigurable Intelligent Surfaces (RISs)
主讲人： Prof. Marco Di Renzo (CNRS & Paris-Saclay University)
https://www.bilibili.com/video/BV1wk4y117yR
RIS 前沿技术系列讲座(五)： 如何用可重构智能表面实现智能的无线世界
主讲人： 黄崇文 博士 (SUTD)
https://www.bilibili.com/video/BV1yK4y187K7/?spm_id_from=333.788.videocard.3
RIS 前沿技术系列讲座(六)： Reconfigurable Intelligent Surfaces (RIS) Aided Multi-user Systems: Interplay Between NOMA and RIS
主讲人： Dr. Yuanwei Liu (Queen Mary University of London)
https://www.bilibili.com/video/BV1aa4y1L7cL
RIS 前沿技术系列讲座(七)： RIS-based Communications for 6G Wireless Networks
主讲人： Assoc. Prof. Ertugrul Basar (Koc University)
https://www.bilibili.com/video/BV1QK4y1h7g8
RIS 前沿技术系列讲座(八)： 智能反射表面（IRS）通信中的传输方案设计
主讲人：潘存华 助理教授 (Queen Mary University of London)
https://www.bilibili.com/video/BV1fi4y1j7AL/?spm_id_from=333.788.b_7265636f5f6c697374.5
RIS 前沿技术系列讲座(九)： RIS 在无线通信中的部署场景及挑战
主讲人：袁弋非 博士 (中国移动研究院)
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RIS 前沿技术系列讲座(十)： Algorithm Design for IRS-Assisted Wireless Communication Systems
主讲人：Dr.Xianghao Yu (Friedrich-Alexander-Universität Erlangen Nürnberg)
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RIS 前沿技术系列讲座(十一)： 人工超构材料多维电磁场的调控研究
主讲人：李龙 教授 （西安电子科技大学）
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RIS 前沿技术系列讲座(十三)： 智能超表面赋能通信技术的挑战与机遇
主讲人：袁晓军 教授 （电子科技大学）
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