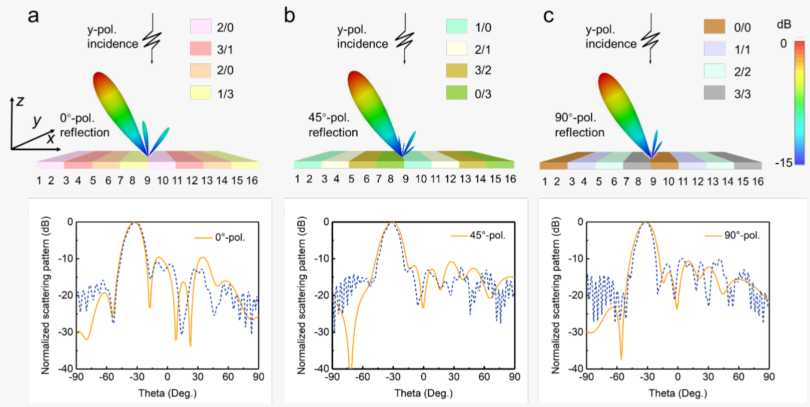
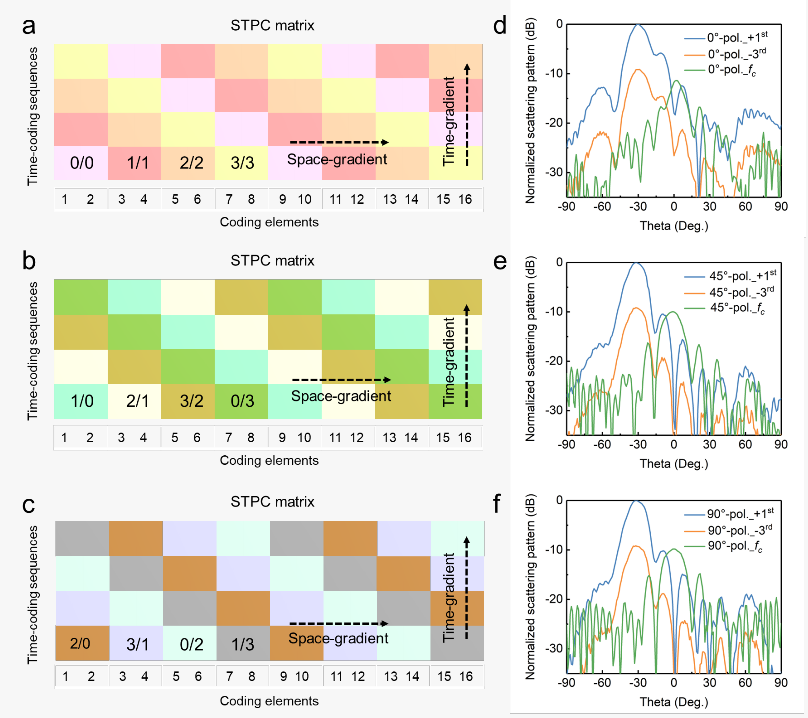
Arbitrarily rotating polarization direction and manipulating phases in linear and nonlinear ways

USA, September 2, 2024 /EINPresswire.com/ -- Independent controls of various properties of electromagnetic (EM) waves are crucially required in a wide range of applications. Towards this goal, scientists in China proposed the concept and general theory of space-time-polarization-coding (STPC) metasurface, which adds the functionality of arbitrarily controlling polarization direction compared to space-time-coding (STC) metasurfaces. The proposed approach has a wide range of applications in various areas, such as imaging, data storage, and wireless communication.



The simulated normalized 3D scattering patterns of (a) 0°-, (b) 45°-, (c) 90°-polarized reflection at 3.5 GHz.



2D STPC matrices and measured normalized far-field scattering patterns.

Independent manipulations of various properties of EM waves are crucially required in a wide range of applications. Metasurface is a promising candidate to provide an advanced platform for manipulating EM waves. In 2014, the concepts of digital coding metasurfaces and programmable metasurfaces were first put forward, effectively integrating metasurfaces technology with information technology.

This greatly simplified the design process of metasurfaces and laid the foundations for their development and application in radar systems, wireless communication, and EM imaging. Recently, time-domain digital-coding metasurfaces and STC metasurfaces have been proposed, enabling simultaneous manipulation of EM waves in both time and space dimensions, significantly extending their research directions and application. As the investigation moved forward, metasurfaces capable of controlling EM waves in multiple dimensions have gradually become a development trend. However, the existing research remains lack the dimension of polarization manipulation.

In a new paper (https://doi.org/10.1038/s41377-024-01513-2) published in Light Science & Applications, the team of the Professor Tiejun Cui from the State Key Laboratory of Millimeter Waves, Southeast University, China have proposed an approach that can arbitrarily control the polarization direction and phases of reflected waves in linear and nonlinear ways using a stacked programmable metasurface. Significantly, they achieved a high polarization rotation range covering the entire azimuthal angles, with a theoretical conversion efficiency of 100% for arbitrary polarization directions.

Further, by extending the STC theory to incorporate the dimension of polarization, they proposed the concept and general theory of STPC metasurface, enhancing the capability to control polarization compared to STC metasurfaces. This provides an extra degree of freedom for manipulating EM waves and significantly expands the range of applications for metarsurfaces. As proof-of-principle application examples, they achieved polarization rotation, phase manipulation, and beam steering at linear and nonlinear frequencies. The proposed approach paves the way for multi-dimensional manipulation of EM waves and has a wide range of applications in various areas, such as imaging, data storage, and wireless communication.

The STPC metasurface composed of two substructure units with different transmission/reflection characteristics was designed to be stacked vertically. By separately modulating the control voltage of varactor diodes oriented at the x- and y-directions, they achieved a high polarization rotation range covering the entire azimuthal angles at linear and nonlinear frequency, as well as adjustable phase. These scientists summarize the operational principle of their STPC metasurface:

“The Jones matrix of the STPC metasurface's reflection characteristics is the product of the Jones matrices of the two substructures' transmission/reflection characteristics. The polarization and phase are controlled through voltages in two orthogonal directions. The simultaneous modulations of the beam and polarization direction of the fundamental wave are achieved using the space-polarization-coding scheme. In addition, simultaneous modulations of the beam and polarization direction of the nonlinear harmonics are achieved using the STPC scheme.”

“Compared to STC metasurface, the STPC metasurface adds the functionality of arbitrarily controlling polarization direction, which provides an extra degree of freedom for manipulating EM waves and significantly expands the range of applications for metarsurfaces. Our approach opens new avenues for the multidimensional manipulation of EM waves. Although the designed STPC metasurface operates in the microwave band, the proposed concept can be extended into terahertz and even optical domains, which have promising applications in radar, imaging, and wireless communications." they added.

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