SC06 - Metasurfaces: Passive, active and applications in antenna design

Abstract:

As a two-dimensional version of metamaterial, a metasurface is constructed by numerous meta-atoms with specific responses of phase, amplitude and polarization in microscopic manner. Since the meta-atoms are usually in sub-wavelength scale, metasurfaces exhibit exceeding ability for beam tuning (including but not limited to beam scanning, beam forming) compared to antenna arrays, where the antenna elements are usually in wavelength scale. From this point of view, metasurfaces provide a new alternative for antenna beam tuning. Additionally, by integrating PIN / varactor diode to meta-atom design, more physical parameters can be tuned and programmed, including but not limited to transmission / reflection amplitude, phase, and polarization. Both passive and active metasurfaces provide a new view to beam tuning and thus are very important to antenna design. In this short course, we would like to introduce basic concept of metasurface, and the phase and amplitude response would be shown through full wave simulation results. Finally, we will focus on the application of metasurfaces in antenna design.

Recommended pre-requisites:

The course requires knowledge of electromagnetism, and some basic understanding of antenna design and microwave transmission lines.

Learning Objectives:

For this short course, both instructors are specialized in antenna and microwave engineering, and they have devoted more than 10 years to the field of metasurfaces. The aim of this short course is to establish the basic concept of metasurface for people working in the antenna domain and show them how metasurface concept can be employed to enhance antenna performances. Thus after the tutorial entitled "Passive and active metasurfaces: Applications in antenna design", we expect the participant would have

(1) the knowledge of both passive and active metasurfaces: We will start from passive metasurfaces, including the physical configuration, the amplitude and phase response of S-parameters with the functionalities of beam tuning and then we will introduce the basic principle of active meta-atom and tuning method.

(2) the simulation methods of meta-atoms: We will show by commercial software (CST or HFSS) the simulation model (input and output ports, boundary conditions, and so on) of meta-atoms. Also we will talk about the influence of geometric parameters on the transmission characteristics (amplitude, phase and polarization). Bias control circuit design will be discussed for the active meta-atom.

(3) the application of metasurfaces in antenna design: Here, two types of metasurface antenna will be introduced. The first one is the separate configuration, namely the metasurface is used as a lens to enhance the antenna performance, such as narrow beam with high directivity. The second is the integrated design of both antenna and metasurface. Also, we will present the evolution of metasurfaces in antenna domain.

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Course Outline:

In this tutorial, we would like to give a full view on metasurfaces, including concept, simulation method, antenna application scenarios. We would propose the program as follows:

(1) Basic concept: explain the physical construction of metasurface, and the macroscopic electromagnetic response.

(2) Full wave simulation: show the design procedure of (a) passive multi-layered stacking metasurface, which can be tuned by judicious phase modulation, and (b) active PIN / varactor diode loaded metasurface, which can exhibit tunable phase and amplitude response under different bias voltages.

(3) Application of metasurface in antenna design: discuss the metasurface with antenna performance, including separate and integrated prototypes, and finally

(4) Explain the kaleidoscopic wavefront control by active metasurface platform.

Instructors

Kuang Zhang (Member, IEEE) received the B.Sc. degree in electronics and information engineering, the M.Eng. degree in electronics engineering, and the Ph.D. degree in communication and information systems from the Harbin Institute of Technology (HIT), Harbin, China in 2005, 2007, and 2011, respectively. He worked as a visiting professor with the University of Wisconsin-Madison, Madison, WI, USA, from 2015 to 2016, and a guest professor with Univ Paris Nanterre in 2018. Since 2010, he has been with the Department of Microwave Engineering, School of Electronics and Information Engineering, HIT, where he is currently a full professor. He has published more than 100 papers, including 4 on Nature Communications, and more than 20 on IEEE Transactions serial jounals. All these paper has been cited for more than 6000 times in Google Scholar. He has won 3 prizes for the contributions to metasurface design (2010, 2018, 2024). He is selected at the top 2% Scientists Stanford University, and also the most cited Chinese researchers by Elsevier. He firstly proposed the concept of chirality-assisted phase and applied this phase resource to the wavefront decoupling.

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Shah Nawaz Burokur (Senior Member, IEEE) received his PhD degree from the Université de Nantes (France) in 2005. He is currently an Associate Professor with the Université Paris Nanterre (France) and is involved in the design of microwave devices based on the transformation optics concept. He has authored or co-authored one book on transformation optics-based antennas, six book chapters, and more than 200 articles in scientific journals and holds three patents on metamaterial-based and inspired antennas. His current research interests include microwave and applications of periodic structures, complex media, metamaterials, metasurfaces, and metagratings, in the analysis of integrated planar and conformal circuits, antennas, sensors, orbital angular momentum, and holographic imaging.

Key Bibliography

(1) DOI: 10.1126/science.1210713
(2) DOI: 10.1109/TAP.2007.895567
(3) DOI: 10.1038/s41467-020-17773-6
(4) DOI: 10.1002/adma. 201405047
(5) DOI: 10.1038/s41467-025-60956-2
(6) DOI: 10.1038/s41467-024-50560-1
(7) DOI: 10.1109/TAP.2025.3575275