Nonreciprocal Phased-Array Antenna Systems

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Abstract

This talk describes the concept and experimental demonstration of nonreciprocal phased-array antennas able to exhibit (i) an independent control of their transmission and reception patterns at the same operation frequency; and (ii) nonreciprocity at the polarization level, i.e., the antennas transmit with one polarization but receive with the opposite handedness. The proposed approach can be applied to develop efficient nonreciprocal phased-array antennas across the electromagnetic spectrum and find broad applications in wireless communication and polarimetric radar and sensing systems.

1. Summary

Magnetless nonreciprocity [1] has recently attracted significant attention to realize a wide variety of CMOS-compatible devices such as isolators [2], circulators [3], and filters [4,5] operating from radiofrequencies to the infrared and telecom wavelengths [6,7]. However, these techniques have mostly been applied to develop *nonreciprocal guided components* whereas little attention has so far been devoted to *nonreciprocal antennas*. Such devices have the potential to significantly impact wireless communication, radar, and sensing systems by enabling an independent manipulation of their transmission and reception patterns, including polarization, at the same operation frequency. The prospective applications of such devices are enormous: from enhanced channel capacity in MIMO radio links and radar systems able to effectively handle jamming signals and strong interferences to polarimetric sensors with boosted performance that do not interfere the environment that they are monitoring.

Very recent efforts in the field of nonreciprocal antennas have been focused on spatio-temporally modulated leaky-wave structures [8-10] that exploit space-time transition to provide isolation between transmission and reception in specific directions in space. Unfortunately, it is challenging to manipulate the radiation pattern and polarization of leaky-wave antennas at a fixed frequency, and these devices are usually bulky and with little use in practice. Other option could be to connect a standard antenna, like a planar Yagi-Uda, with a nonreciprocal band-pass filter based on spatio-temporal modulation [11]. Even though this approach provides over 20dB of isolation between transmission and reception that can be reversed at will, it lacks reconfiguration schemes to favor specific directions in space. In this context, it should be mentioned that several types of time-modulated metasurfaces have recently been put forward [12-15] to manipulate plane waves propagating in free-space, including frequency translation and nonreciprocal reflection/refraction at fixed spatial directions.

In this invited talk, we will discuss a new type of nonreciprocal component recently developed in our group: *phased-array antennas able to independently manipulate their transmission and reception patterns at the same operation frequency [16]*. Our approach is based on merging time-modulated resonators with high-Q structures –such a patch antennas– to achieve very efficiency conversion between only two frequencies (one related to waves in free-space and other to guided signals) and then taking advantage of the photonic Aharonov-Bohm effect [17] to control in a nonreciprocal manner the relative phases of the fields radiated/received by the elements of the array. We will demonstrate isolation over 40dB at desired, tunable directions in space using a simple 2 element phased-array system at 2.4 GHz, with important implications in the next generation of radar and wireless communication systems.

Furthermore, *we will theoretically and experimentally demonstrate that a single antenna element can exhibit nonreciprocity at the polarization level* – i.e., transmit waves with one polarization but receive waves with opposite handedness [18]. Nonreciprocal polarization control has critical implications in sensing systems. For instance, let us consider an antenna radiating right-handed circularly polarized (RHCP) waves. Upon a simple reflection on a metallic screen, such waves acquire a left-handed circular polarization (LHCP) and thus cannot be effectively received by the same antenna. Antennas with nonreciprocal polarization handedness are perfectly suited to receive circularly polarized waves reflected on metallic surfaces and, more broadly, to test the polarization response of unknown objects. Our efforts constitute a significant step forward in the state of the art of polarimetric systems, which usually require independent transmit and receive antennas prone to misalignments, and find exciting applications in sensors and weather radars among many others.

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