The Role of Electronically Reconfigurable Reflectarrays, Transmitarrays, and Metasurfaces in Future Phased-Array Antenna Applications

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Phased-array antennas are widely used in various communications, radar, and electronic warfare systems. Compared to mechanically beam-steerable antennas, they provide significantly faster beam steering and more functionalities albeit at the expense of added cost and complexity of design. Phased-array antennas can be categorized into active and passive electronically steered arrays (AESAs and PESAs). In an AESA architecture, each array element is backed by a transmit/receive (T/R) module that includes a complete RF transceiver chain. AESAs are capable of performing sophisticated beamforming and spatial filtering using digital beamforming techniques. In contrast, a PESA architecture is characterized by having one or a few RF transceiver chains that feed the array elements using a passive feed network. Each array element uses a phase shifter and possibly an amplitude control mechanism to perform beam steering. PESAs are generally less capable than AESAs but offer a comparatively simpler system architecture. With the development and proliferation of low-cost microwave and millimeter-wave silicon-based T/R modules, however, the cost of developing AESAs has significantly decreased and they are being deployed at an ever-increasing rate, particularly in consumer wireless communications applications. It is likely that AESAs will dominate the future of phased-array antenna market, at least in terms of the number of units deployed.

One method of developing PESAs that has received a significant attention in recent years is the use of reconfigurable reflectarrays, transmitarrays, and metasurfaces to perform beam steering. These devices consist of periodic or quasi-periodic electromagnetic structures whose responses can be electronically tuned using electronic switches, varactor diodes, or numerous other means. Developing phased-array antennas is one of the application areas that has motivated the development of these structures. In light of the significant growth in the development of silicon-based T/R modules, an interesting question arises: What is the future role of reconfigurable reflectarrays, transmitarrays, and metasurfaces in phased-array antenna development? In this presentation, I answer this question based on our team's experiences working on developing electronically reconfigurable reflectarray and transmitarray antennas for phased-array applications at the University of Wisconsin-Madison (UW). I will first discus the characteristics of the applications where PESAs can compete well with AESAs. I will then present two specific applications that have motivated our work in this area in recent years. These include very-high-power radar/EW as well as communications on the move applications. AESAs are currently not a viable contender for the former application and are potentially at a disadvantage for the latter one. I will present a number of different electronically-reconfigurable reflectarray and transmitarray antennas that are either under development or have been developed at UW for these two applications. Important aspects of these designs including power handling capability, thermal management issues, and design of digital control circuitry will also be discussed. Finally, I will briefly discuss a few other emerging application areas in which electronically reconfigurable reflecarrays and transmitarrays may compete well.