Metasurface Antennas in Computational Imaging and Security-Screening

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The use of microwaves and millimeter-waves for imaging has been the subject of much research in the literature. A significant advantage of these modalities is that the radiation in these frequency bands is non-ionizing, making these techniques suitable to be employed in a vast number of applications, including security-screening, non-destructive testing and biomedical imaging. Recently, emerging RF imaging modalities leveraging the concept of computational imaging have attracted significant attention. Much of this interest is due to the fact that computational imaging can obtain comparable performances to conventional systems, such as synthetic aperture radar (SAR) and phased arrays, but with significantly faster data acquisition and a simpler physical sensing architecture.

Over the last few years, our group at Duke University has demonstrated imaging with both frequency-diverse metasurface antennas as well as dynamically reconfigurable metasurface antennas, leveraging computational imaging techniques. Frequency-diverse antennas are defined by their ability to generate spatially-distinct radiation patterns as a function of excitation frequency. These complex waveforms can be used to illuminate a scene and encode its spatial content into simple backscatter frequency measurements. The resulting signals are post-processed through computational techniques to obtain high-quality images of the scene. In this manner, frequency-diverse apertures can replace cumbersome and cost-prohibitive systems that rely on mechanical scanning or electronic beamforming, while obtaining comparable image quality within a fraction of the acquisition time. In addition, frequency-diverse antennas are planar, do not rely on moving parts, and can be fabricated using standard printed circuit board (PCB) technology. Given these advantages, they have gained traction for security screening and threat detection at microwave and millimeter-wave frequencies.

In this work, we review two primary outcomes of our efforts: a) metamaterial antennas which rely on subwavelength metamaterial radiators with resonant frequencies distributed across an operational bandwidth and b) planar cavities, which take advantage of frequency-diverse modes supported within an electrically-large cavity to form distinct radiation patterns. The principles of operation, as well as the advantages and disadvantages, of both methods are discussed and high-quality images are presented. A complete imaging system, consisting of multiple frequency-diverse apertures as transmitters and receivers, intended to image human-sized objects is also presented. The hardware platform, customized RF circuitry, and the critical role of RF calibration are discussed. Experimental reconstructions of human-size targets with threat objects are shown using the proposed system.

In addition, we discuss methods of introducing dynamic reconfigurability into the metasurface aperture, resulting in an antenna capable of dynamic beamforming but with far lower cost and many other advantages compared with phased array or electronically scanned antenna (ESA) systems. We show images taken with the dynamic metasurface aperture, and discuss the tradeoffs with respect to the frequency diverse aperture.