Adapting Range Migration Techniques for Fast Image Reconstruction with Metasurface Antennas

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Electromagnetic metamaterial technology uses subwavelength tunable radiators embedded in a waveguide antenna in order to generate high quality beams that can be used from satellite communications to microwave imaging, with no moving parts. This technological innovation results in an antenna that creates vast opportunities for security screening, through wall imaging and medical diagnosis. Particularly in synthetic aperture radar (SAR) imaging. While the frequency sampling of any object's backscattered signal can be used to locate objects along the range coordinate, the inherent curvature of the illuminating and scattered wavefronts removes the simple Fourier transform relationship between the frequency and range variables. However, as the frequency and spatial wavenumber along the range direction are connected through the free space dispersion relation, a resampling of the data is required known as Stolt interpolation that restores the relationship, enabling fast Fourier transforms (FFTs) to be applied in image reconstruction. This approach, known as the Range Migration Algorithm, drastically reduces processing times and storage requirements, making it very useful for SAR imaging. Unlike in this imaging scenario, when the metasurface is used, the backscattered signal is not measured from a single point along the aperture path, but rather measured at all points at the same time for different tuning states. Therefore, the signal is encoded in the diverse beams that illuminate the scene, and the spatial dispersion (which permits the use of the RMA) cannot be applied. The use of metasurface antennas in imaging systems simplifies the physical hardware and can increase the data acquisition rate. However, they do not generate uniform radiation patterns; further, they do not provide information that can be directly transformed in the Fourier basis. In this work, we propose to separate the role of the dynamic metasurface from the backpropagation of the signal. In this sense, we use the various tunable states to estimate the measurements that would be produced by conventional sampling. With the dynamic metasurface, the measured signal must be transformed as if it were the signal measured with an array of independent dipolar antennas. This can be accomplished using the antennas experimental characterization or with a predictive analytic model. Different numerical studies illustrate imaging performance of this adapted RMA, demonstrating that we can reconstruct images with a dynamic metasurface in a fraction of the time when compared with computational imaging techniques.