“Quantum OAM-Enhanced Radar and Microwave Communications”

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AY 2019-2020 Progress Report

Background & Significance

Control of orbital angular momentum (OAM) in microwaves is of interest to NASA for increasing radar sensitivity and communication spectral efficiency. OAM is characterized by an integer OAM mode where zero represents the case of a plane wave. Microwaves with a nonzero OAM mode propagate with a helical wavefront. OAM modes are mathematically orthogonal and can theoretically be used to carry distinct information at the same frequency and polarization, increasing the data rate. The OAM waveform may also increase radar detection capability for certain shaped objects. OAM can be induced by broadcasting a plane wave through a spiral phase plate (SPP) dielectric which introduces an azimuthally dependent phase delay. However, SPPs are frequency-specific, which presents an obstacle for harnessing OAM in frequency-modulated communication systems and wide-bandwidth radar. This Fellowship has enabled the development of two circular phased array methods for synthesizing the desired helical wavefront. This approach offers a critical advantage: the phases of all antenna elements are programmable across different frequencies. As a result, transmission and reception of the OAM beam can be controlled over a wide frequency spectrum.

Project Goals

This 2019-2020 Fellowship from the Vermont Space Grant Consortium and NASA EPSCoR has funded Daniel Orfeo’s research and education. Scientific and professional goals and outcomes of this fellowship include:

- **Presentation at IEEE PAST 2019**
  Orfeo orally presented portions of this research at the 2019 IEEE International Symposium on Phased Array Systems and Technology in Waltham, Massachusetts.
- **Publication as conference proceedings**
  This research has been reported in conference proceedings in the following forms:
  - Daniel J. Orfeo, Dylan Burns, Dryver R. Huston, Tian Xia, "Electrically controlled phased array OAM radar," Proc. SPIE 11408, Radar Sensor Technology XXIV, 1140810 (18 May 2020); https://doi.org/10.1117/12.2559388
  - Orfeo D, Burns D, Xia T, Huston D. (2019) “Phased Array for Control of Orbital Angular Momentum in Microwave Systems” IEEE International Symposium on Phased Array Systems and Technology, Waltham, MA, USA
  - Orfeo D, Ezequelle W, Xia T, Huston DR. (2019) “Orbital Angular Momentum Assisted Ground Penetrating Radar” SPIE Defense + Commercial Sensing Symposium Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XXIV, paper no. 11012-47, Baltimore, MD, DOI:10.1117/12.2520545
- **Planned submission to Journal of Applied Remote Sensing**
  This research is in preparation for submission to the Journal of Applied Remote Sensing.
- **Continued progress towards completion of Ph.D.**
  Passed Ph.D. proposal March 2020. Anticipated graduation in October 2020.

Summary of Key Findings

The continuous phase front of the vector potential (**A**) of an OAM waveform can be approximated using a circular phased array of as few as three discrete antenna elements (Figure 1a). This provides motivation for performing microwave simulations and laboratory tests using circular phased arrays with three to eight elements. An 8-element circular phased array is then used to simulate a waveform with nonzero orbital angular momentum (Figure 1b). In this simulation, gigahertz-frequency OAM modes (-1,0,+1) can be received and distinguished, demonstrating the concept of OAM-mode modulated information transmission. In addition, simple OAM waveform scattering is simulated for the case of a spherical target (Figure 1c). A benchtop simultaneous phased array system was designed and built to enable verification of fundamental simulation results. A 750 MHz OAM waveform was found to behave consistently with simulation predictions, as well as with the Laguerre-Gaussian helix model. Finally, a laboratory experiment leverages superposition to demonstrate the function of a synthetic wideband OAM radar using a network analyzer. The concept of a spiral phase plate dielectric lens has been adapted to a spiral reflector used to detect a specific OAM mode at a specific frequency (Figure 1d). It is found that combining individual magnitude and phase measurements can reproduce the behavior of OAM waveforms generated by a simultaneously transmitting phased array. This indicates that a system based on a network analyzer may be a viable path forward for the development of a wideband OAM radar.

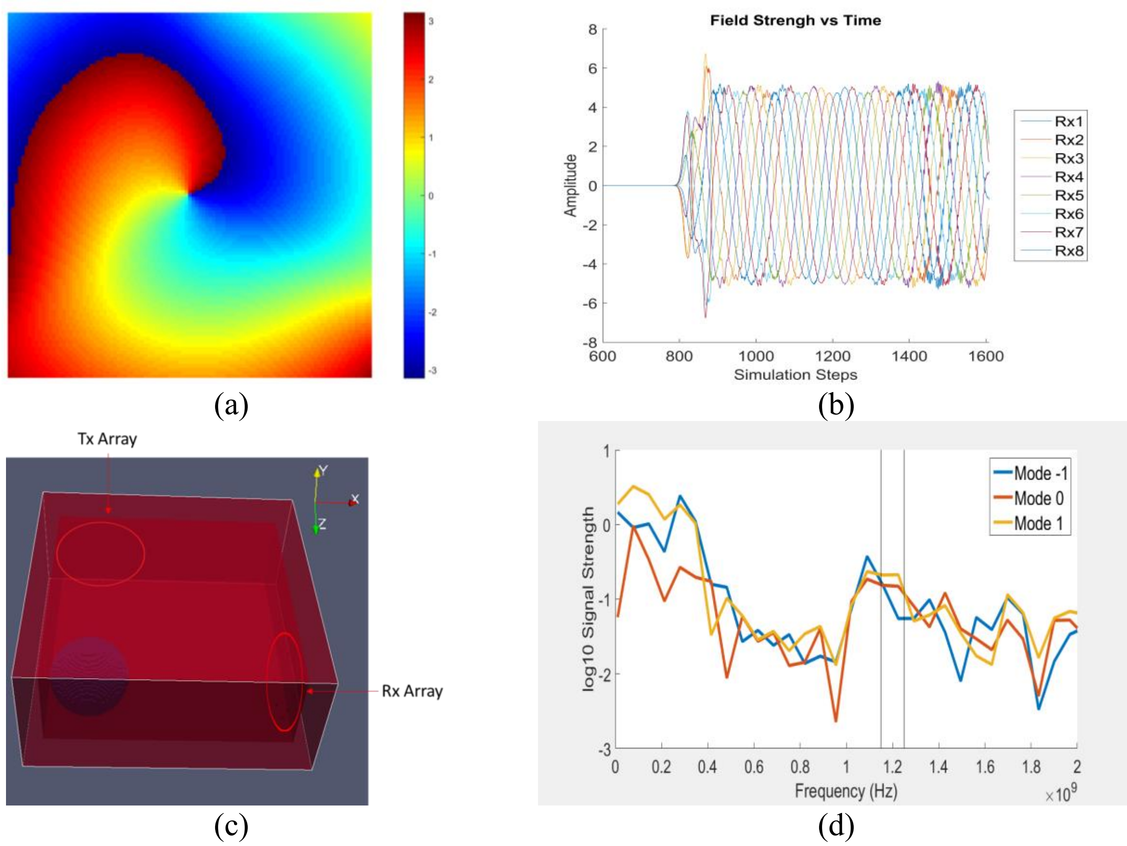

Figure 1 (a) The phase front of **A** *for a 3-antenna circular phased array. (b) Eight sine waves are transmitted in a simulation to produce an OAM +1 (left-handed single helix) waveform. (c) An 8-element transmitter array and 8-element receiver array are used to model OAM waveform scattering from a spherical Perfect Electric Conductor target. (d) Right-handed spiral target at 1-meter distance. Signal magnitude near 1.2 GHz is greatest when the incident signal is post-processed with OAM +1 phasing, confirming the behavior of the OAM waveform.*