Emon

Dr. Frank Robey, FIEEE, FMSS
Featuring: Dr. Bartlett Russell, Ms. Filagot Taye, Mr. John Bauer

Emon will explore tensor radar waveform methods

Disruption Opportunity
Information Session

December 16, 2024

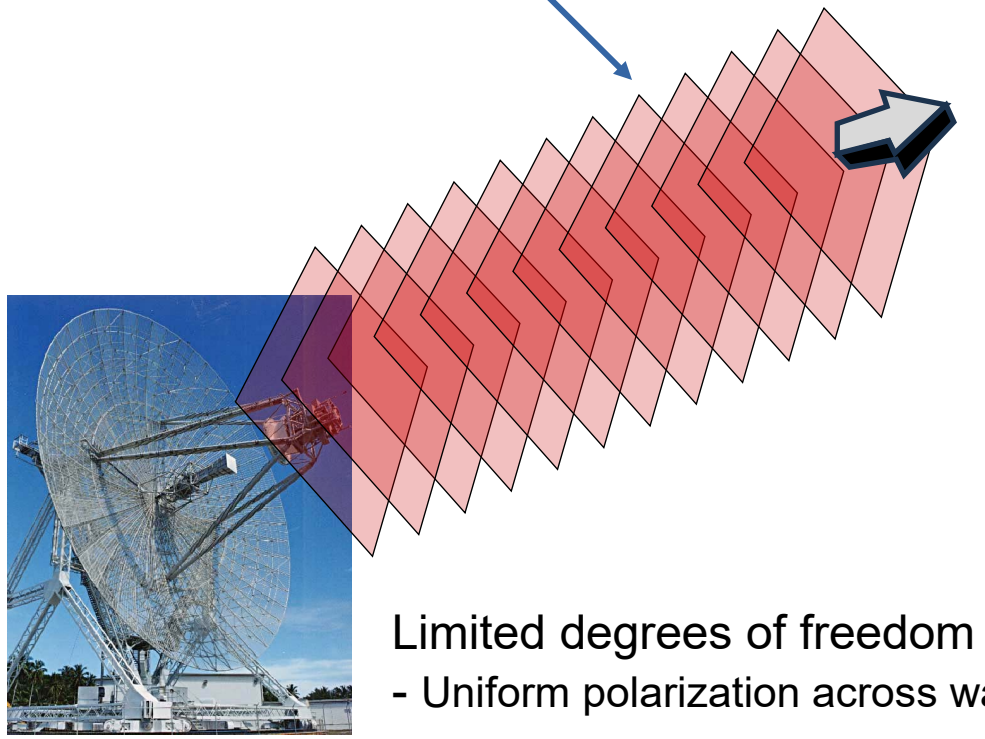
Outline

- Welcome
- Introduction to DARPA Defense Science Office – Bartlett Russell
- Emon Introduction – Frank Robey
- Security Considerations – Filagot Taye
- Emon Contracting – John Bauer

Introduction

Conventional

Standard planar phase fronts



Limited degrees of freedom
- Uniform polarization across wavefront

Emerging

University of Oklahoma
Horus Radar System

Spatially-varying waveforms possible

Automotive Radar
Enables Autonomous Driving

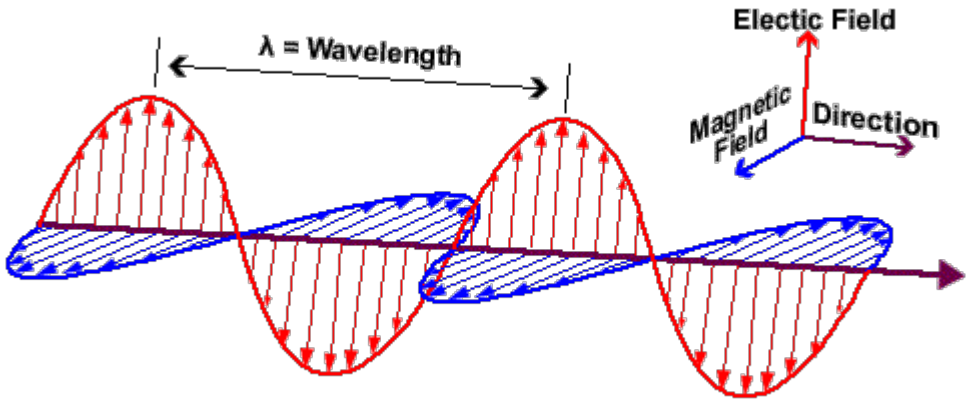
Emon will explore additional DOF possible by spatial modulation of EM field

DOF: Degrees of freedom
EM: Electro-magnetic

ALTAIR Photograph courtesy US Army; Horus Radar courtesy U. Oklahoma
NXP radar: https://www.nxp.com/products/radio-frequency/radar-transceivers-and-socs/tef810x-fully-integrated-77-ghz-radar-transceiver:TEF810X

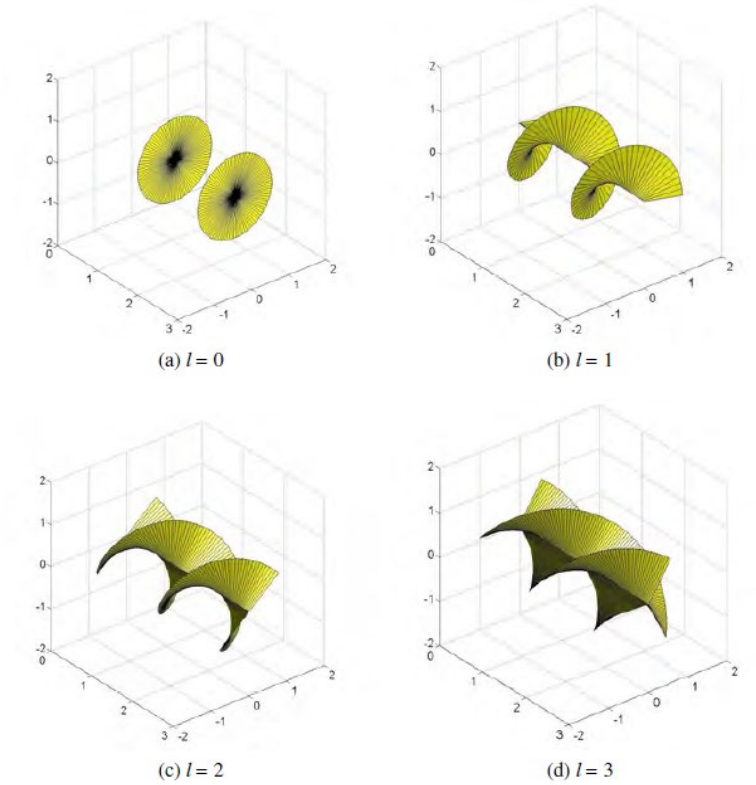
Views of electromagnetic wave propagation

Uniformly planar and polarized waveforms



- With uniform planar polarization, information is encodable in two dimensions
  - Horizontal (H) and vertical (V) basis
  - Receive measurements include co-polarized (HH/VV) and cross-polarized (HV/VH)
  - *Resolution determined by properties of plane wave*

Spatially variant waveforms



- Richer information extraction possible
- Resolution potentially enhanced

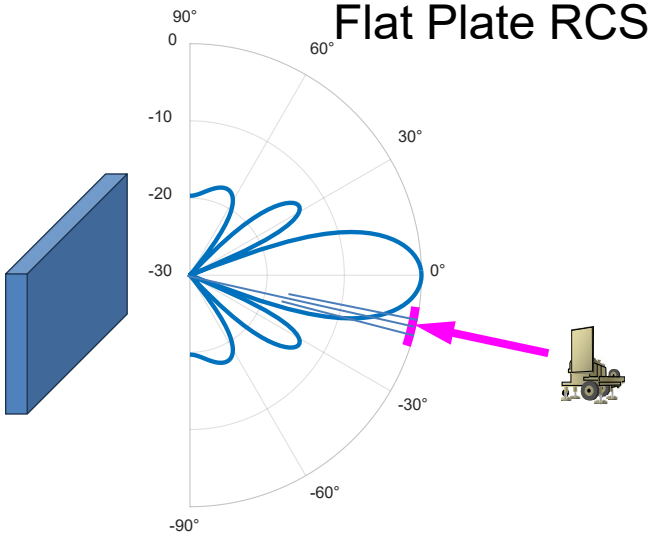
Spatially variant waveform example from: *Angular Momentum of Electromagnetic Radiation*, Sjöholm & Palmer, Diploma Thesis, Uppsala University, Sweden

Fundamental radar attributes

Radar Cross Section (RCS)

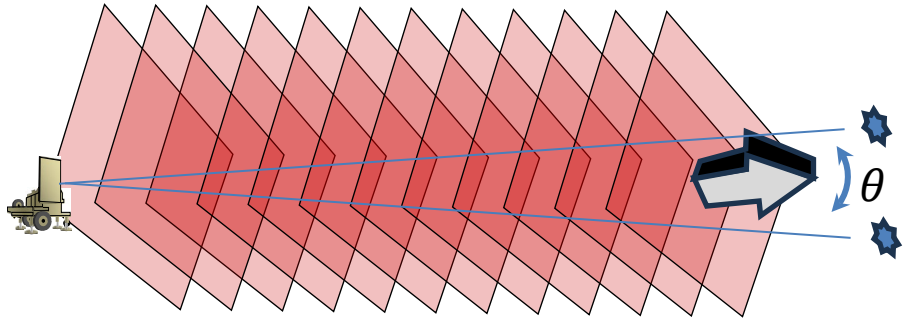
$$SNR = \frac{P_t G_t A_e \tau \sigma}{4\pi R^4 L k T B F}$$

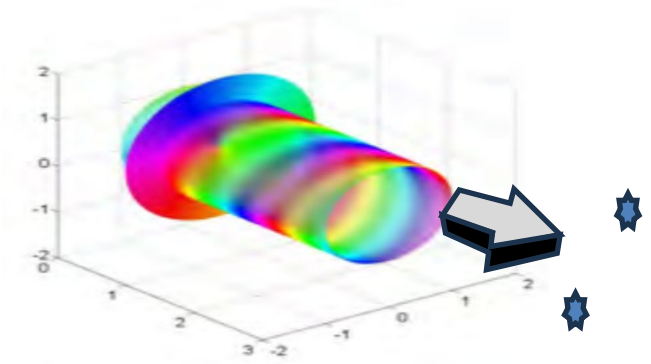
Flat Plate RCS



How do SVW change target RCS?

Resolution: Rayleigh criterion $\theta \approx 1.2\,\lambda/D$

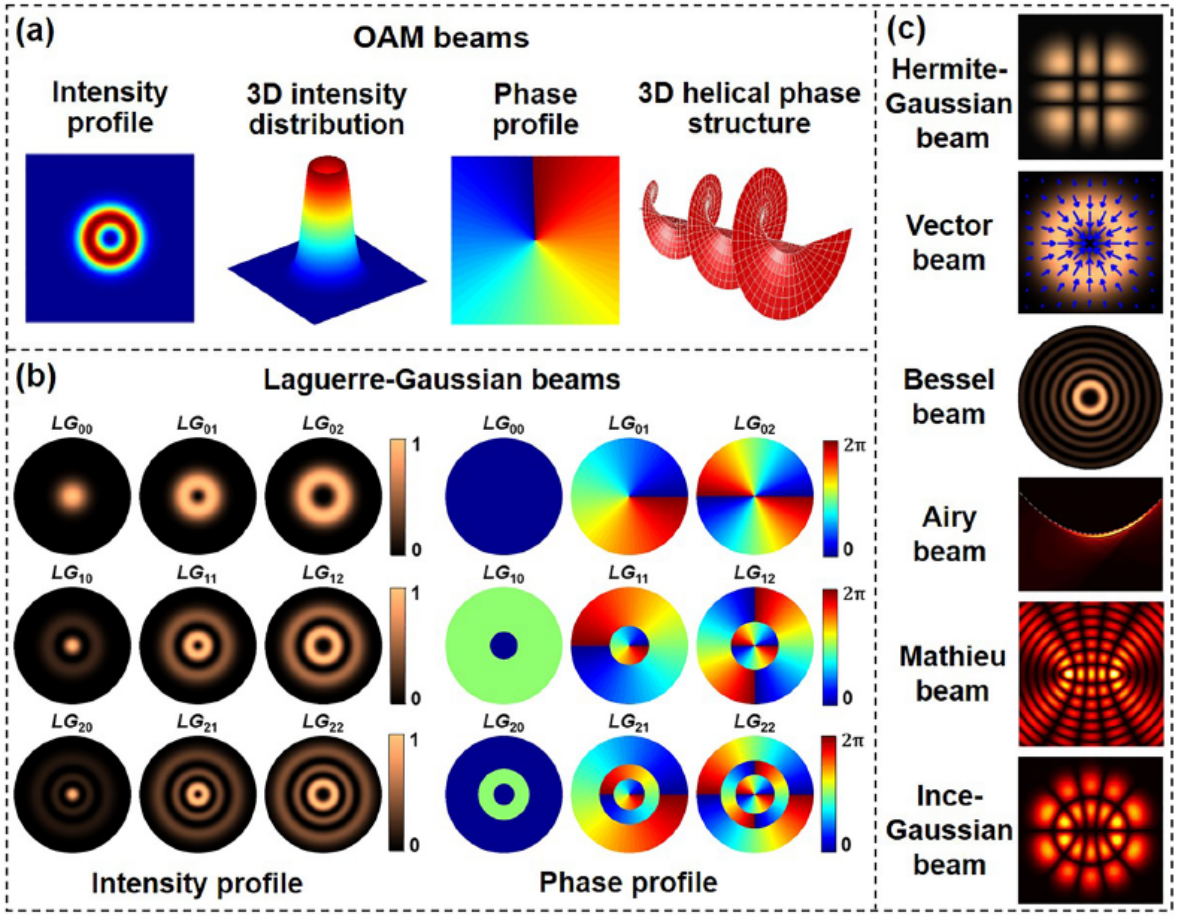




How do SVW change resolution?

RCS: Radar Cross Section
SVW: Spatially-variant waveform

Spatially-variant work in optical domain

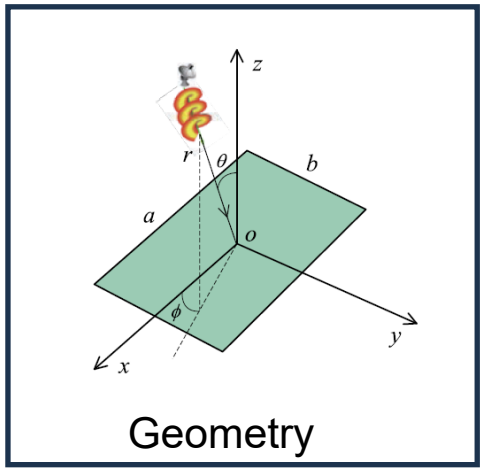


From: Wang, Jian & Liu, Jun & Li, Shuhui & Zhao, Yifan & Du, Jing & Zhu, Long. (2021). *Orbital angular momentum and beyond in free-space optical communications*. Nanophotonics. 11. 10.1515/nanoph-2021-0527

- Extend work from optical domain to radio frequencies (RF)
  - Fundamental physics for two domains are different
  - Waveform/field generation techniques beg exploration to address more complex phenomenology at RF
- Prolate spheroidal basis should produce similar characteristic at radar frequencies

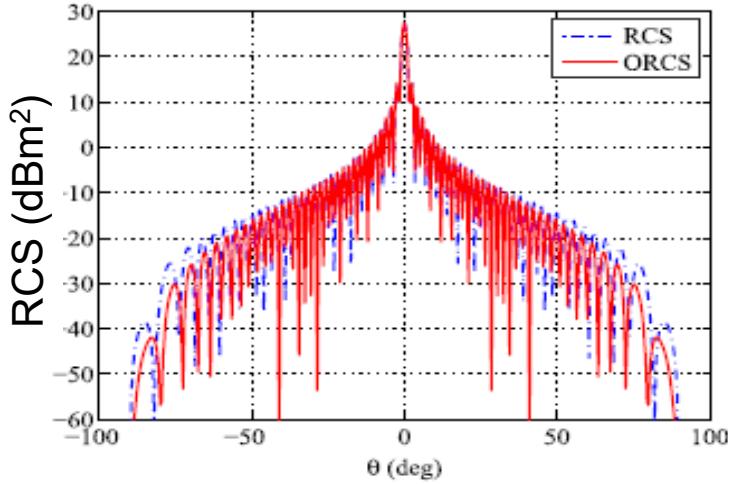
OAM: Orbital Angular Momentum
RF: Radio Frequencies

Early academic investigations

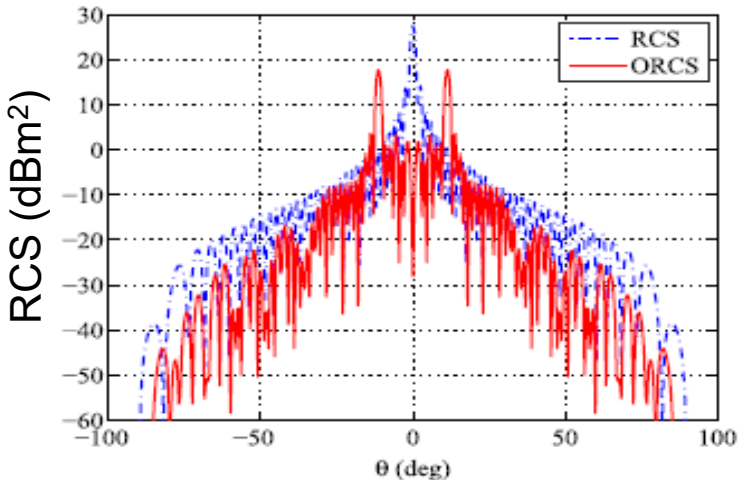


Geometry

Conventional radar

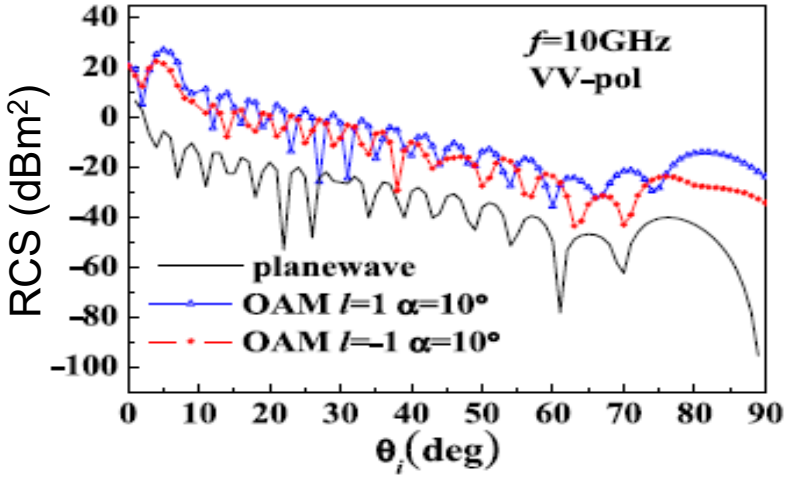


Spatially-variant waveform (OAM)



Spatially-variant modulation can provide scattering properties distinct from plane waves

Dielectric coated plate



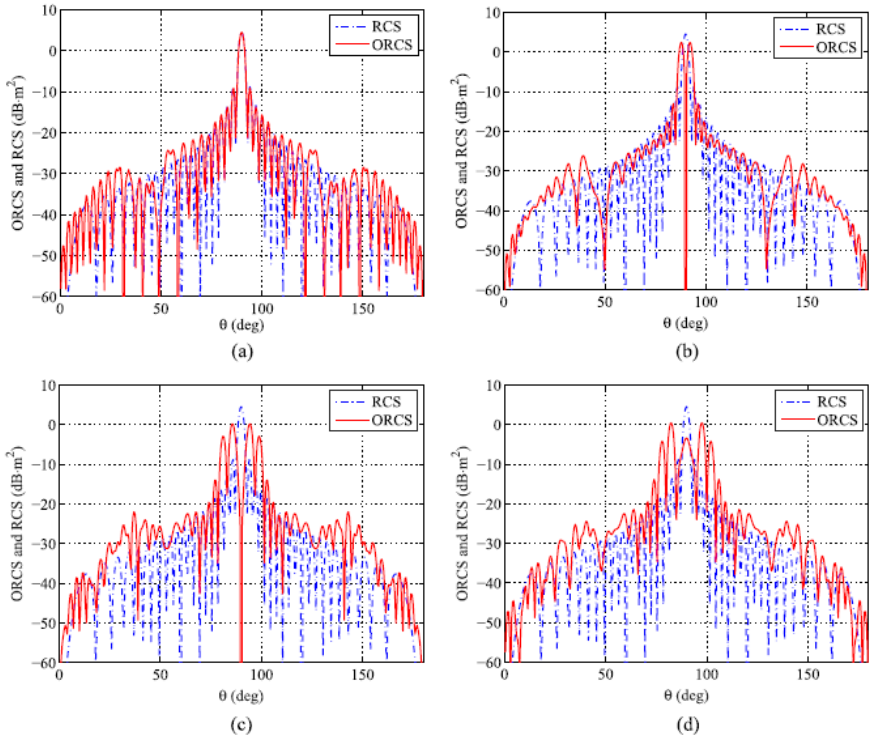
Upper results: K. Liu, Y. Gao, X. Li, Y. Cheng; T*arget scattering characteristics for OAM-based radar*. AIP Advances 1 February 2018

Lower plot: Zhang, et. al, *Analysis of electromagnetic scattering from typical targets for orbital-angular-momentum waves: Theoretical model*, IET, 2022

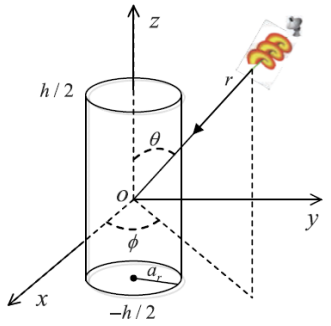
OAM: Orbital Angular Momentum, a specific spatially-variant waveform technique
RCS: Radar Cross Section
ORCS: OAM RCS

Academic investigation for a cylinder

Effect of look angle



Comparisons of ORCS and RCS for the cylinder target ($\phi = 0°$). (a) l=0, (b) l=1, (c) l=3, (d) l=4.



In a manner analogous to, but distinguished from, a flat plate, OAM modes l = 1, 2, 3,… exhibit scattering properties distinct from those of plane waves.

Effect of cylinder geometry

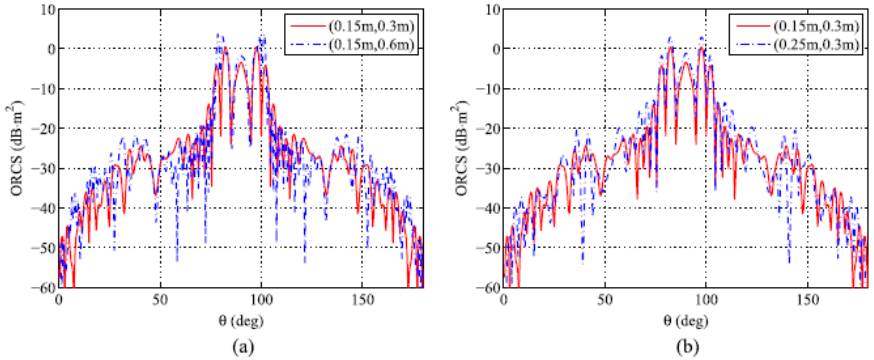


FIG. 11. Influences of the target size on the ORCS ($\phi = 0°$, l=4). (a) Values of ORCS for cylinders with height changing, (b) Values of ORCS for cylinders with radius changing.

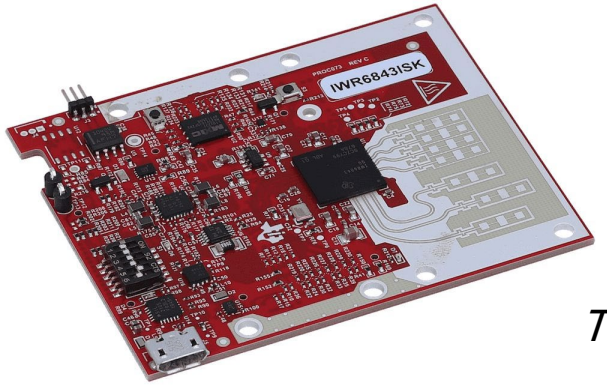
[1]Kang Liu, Yue Gao, Xiang Li, Yongqiang Cheng; T*arget scattering characteristics for OAM-based radar*. AIP Advances 1 February 2018; 8 (2): 025002. https://doi.org/10.1063/1.5018833

OAM: Orbital Angular Momentum, a specific spatially-variant waveform technique
RCS: Radar Cross Section
ORCS: OAM RCS

Program challenges and approach

- Extend optical theoretical framework to RF
  - Waveform Generation
  - Target interaction
  - Signal processing
- Specialized hardware is required to test theory
  - Leverage COTS automotive radar technology
  - Define spatially-variant waveforms
- Fundamental exploration
  - Exploration is constrained to canonical shapes
  - Explore autonomous vehicle application

Automotive/autonomous vehicle radar use case



TI evaluation board

NXP/RFBeam automotive radar module

RF: Radio Frequency
COTS: Commercial Off The Shelf

Program structure/metrics

Single Phase Effort (18m):

- Extend optical theoretical framework to radar
  - Investigate spatial field modulation physics, propagation and target interaction
  - Characterize interaction of novel EM fields with targets of interest via theory
  - Define analogous measures such as *radar cross section*
  - Define processing advances needed to exploit tensor phenomena
- Perform lab/field tests of interaction of tensor fields with targets
  - Determine hardware and control needed to provide agile modulation of spatial fields
  - Develop a class of spatially-variant waveform/transmit modes
  - Integrate test hardware capable of producing multi-modal agile EM fields

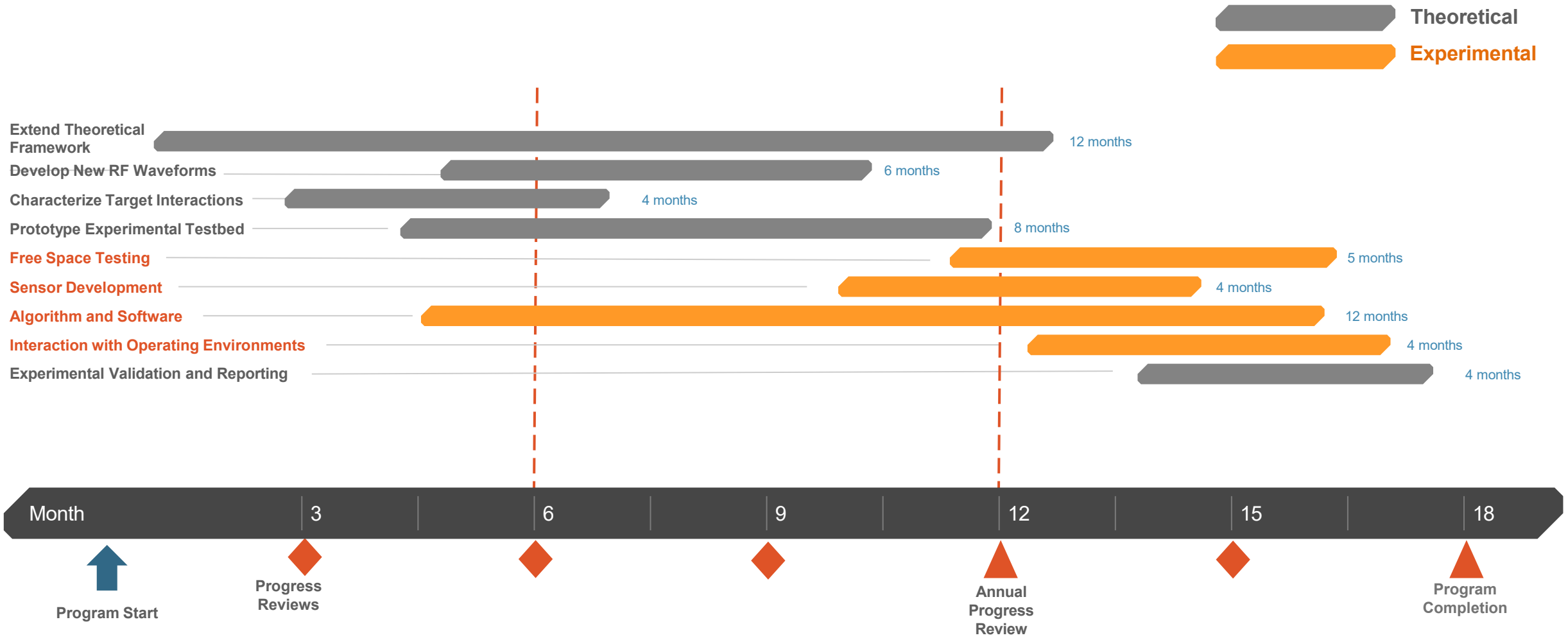
	Metrics
Theory	• Tensor RCS: 3 shapes[1] showing >3dB increase • Resolution: >2X monostatic Rayleigh • Far-field utility[2]: $> D^2/\lambda$
Test	• Demonstrate >2 simultaneous modes as laboratory/field test • >2 targets & distributed/clutter

[1]Potential shapes: cone, pyramid, rod, plane, ogive, conic frustum

[2]Far-field = $\frac{D^2}{\lambda}$ = aperture extent/wavelength

EM: Electro-magnetic

Program structure/notional timeline



RF: Radio Frequencies

Desired Response

Proposals are responsive to the published evaluation criteria.

Proposed team have the resources to do analytical and experimental work

Team will include solid expertise in the following areas:
Radar waveform design from a mathematics and physics viewpoint
Electromagnetic propagation and target interaction
Experimental hardware/software design and implementation
Signal processing
Technical and administrative organization and leadership

Proposer indicates the ability to meet the security guidance in academic environments

Security

CUI Need-to-Know

What is CUI?

CUI is information that the government creates or possesses – or that an entity creates or possesses on behalf of the government that law, regulation or government-wide policy requires or permits an agency to handle using safeguarding or dissemination controls

What governs CUI?

DODI 5200.48 “Controlled Unclassified Information (CUI)” In accordance with Part 2002 of Title 32, CFR, CUI requires safeguarding or dissemination controls identified in a law, regulation, or government-wide policy for information that does not meet the requirements for classification in accordance with E.O. 13526

The National Institute for Standards and Technology (NIST) SP 800-171 rev 2 “Protecting Controlled Unclassified Information in Nonfederal Information Systems and Organizations”

DoDI 8582.01 “Security of Non-DOD Information Systems Processing Unclassified Nonpublic DoD Information”. (Page 7: Breaks down NIST Compliance requirements)

A CUI guide will be provided to describe the information needing protection

Export Control and Non-U.S. Participation

See PA-24-04 Section 7.1.2 for information on participation by non-U.S. organizations and Section 4.2 for information on Fundamental Research

DARPA does NOT have the authority to make Export Control determinations on behalf of Performers

Public Release Information

All Emon CUI (e.g., confidential business information, controlled technical information, operation security) regardless of media or format, will be protected from disclosure to unauthorized persons or groups, by properly storing in locked offices, cabinets, and drawers in accordance with DoDI 5200.48

Proposed public disclosures of unclassified information regarding all DARPA efforts must be processed for approval prior to publication or distribution. Details may be found at: https://www.darpa.mil/work-with-us/contract-management/public-release

A fundamental research exemption to release review will not be provided for this program.

Security Incidents or Concerns

Be aware of the classification level of your material

When reproducing or transmitting materials ensure that it occurs on appropriately cleared system. Ensure all work is on an approved system at the appropriate level

Ensure ALL CUI emails are encrypted

Must notify DARPA DSO Security within 24 hour of any security issues!
DSO_Security@darpa.mil

Contracting

Please pay attention to due dates in Program Solicitation DARPA-PA-24-04-04 and all instructions – Read the Program Solicitation (PS).

Important Dates:

Questions Due: Jan 17, 2025

Proposals Due: Jan 24, 2025, 4PM Eastern Time

See Section 8.2.1 if your organization has not proposed to DARPA previously and note the lead time on new registrations.

Other Transaction (OT) Authority

The Government reserves the right to award an OT for Prototypes under 10 U.S.C. § 4022 or make no award at all.

Not a Request for Proposal (RFP)- FAR Part 15 does not apply.

Not a Broad Agency Announcement (BAA)- FAR Part 35 does not apply.

Use of OTs for Prototypes

10 U.S.C 4022 (d) (1) permits DARPA's OT authority to be used only when one of the following conditions are met:

(A) There is at least one nontraditional defense contractor or nonprofit research institution participating to a significant extent in the prototype project;

(B) All significant participants in the transaction other than the Federal Government are small businesses (15 U.S.C. 638)) or nontraditional defense contractors;

(C) At least one third of the total cost of the prototype project is to be paid out of funds provided by sources other than the Federal Government; or

(D) The senior procurement executive for the agency determines in writing that exceptional circumstances justify the use of a transaction that provides for innovative business arrangements or structures that would not be feasible or appropriate under a contract, or would provide an opportunity to expand the defense supply base in a manner that would not be practical or feasible under a contract.

“Non-Traditional” Defense Contractor

10 U.S.C 3014 Non-Traditional Definition:

Nontraditional defense contractor, with respect to a procurement or with respect to a transaction authorized under section 4022 of this title, means an entity that is not currently performing and has not performed, for at least the one-year period preceding the solicitation of sources by the Department of Defense for the procurement or transaction, any contract or subcontract for the Department of Defense that is **subject to full coverage under the cost accounting standards** prescribed pursuant to section 1502 of title 41 and the regulations implementing such section. To be considered as participating to a significant extent, the proposal should substantiate that the effort being performed by the nontraditional defense contractor is critical to the technical success of the project.

Award Eligibility

In order to receive an award:

Offerors must have a Unique Entity ID (UEI) and must register in the System for Award Management (SAM) at SAM.gov.

Offerors must also register in the prescribed Government invoicing system (Wide Area Work Flow (WAWF): https://wawf.eb.mil/xhtml/unauth/registration/notice.xhtml). DARPA Contracts Management Office (CMO) personnel will provide assistance to those offerors from whom a proposal is requested.

Offerors must be determined to be responsible by the AO and must not be suspended or debarred from award by the Federal Government nor be prohibited by Presidential Executive Order and/or law from receiving an award.

All offerors are required to submit DARPA-specific representations and certifications at the time of proposal submission. See http://www.darpa.mil/work-with-us/reps-certs for further information on required representations and certifications.

Competition Sensitive Information

DARPA policy is to treat all submissions as competition sensitive, and to disclose their contents only for the purpose of evaluation.

Restrictive notices notwithstanding, during the evaluation process, submissions may be handled by support contractors for administrative purposes and/or to assist with technical evaluation.

All DARPA support contractors performing this role are expressly prohibited from performing DARPA sponsored technical research and are bound by appropriate nondisclosure agreements.

Input on technical aspects of the proposals may be solicited by DARPA from non-Government consultants/experts who are strictly bound by the appropriate non-disclosure requirements.

Summary

Emon Summary

- There are many untapped aspects of EM wave propagation that are not currently being utilized

- This program will investigate spatial field modulation physics, propagation and target interaction
  - Determine hardware and control needed to provide agile modulation of spatial fields
  - Explore software and algorithms that would take advantage of created spatially-variant fields

Emon is an early exploration of tensor radar

- We look forward to your participation!

Examples of tensor EM field research

In optics/optical communications

- Willner, Alan E. et al. *Optical communications using orbital angular momentum beams*. Advances in Optics and Photonics 7 (2015): 66-106.
- Sun, Xiaole & Djordjevic, Ivan. (2016). *Physical-Layer Security in Orbital Angular Momentum Multiplexing Free-Space Optical Communications*. IEEE Photonics Journal. 8. 1-1. 10.1109/JPHOT.2016.2519279.
- Wang, Jian & Liu, Jun & Li, Shuhui & Zhao, Yifan & Du, Jing & Zhu, Long. (2021). *Orbital angular momentum and beyond in free-space optical communications*. Nanophotonics. 11. 10.1515/nanoph-2021-0527.

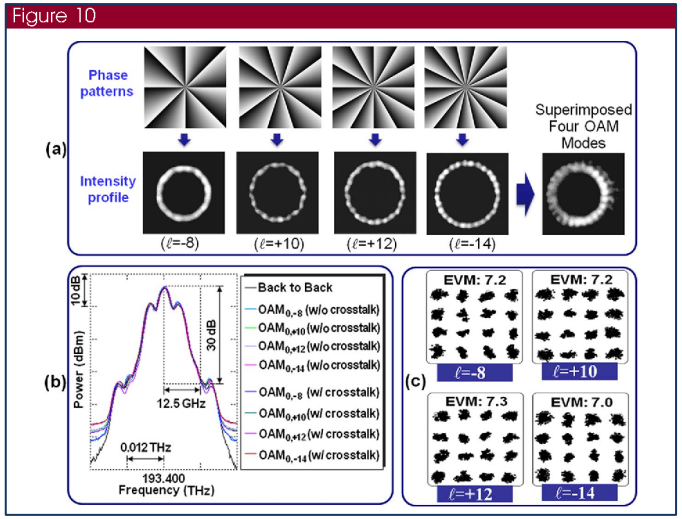


Image from reference 1: *Optical communications using orbital angular momentum beams*

Tensor Electromagnetic Field Generation

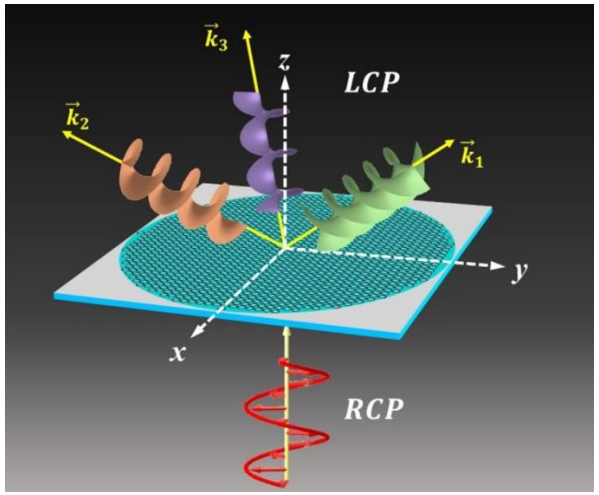


Image from reference 1: *Research of Vortex Electromagnetic Beam Generation and Scattering Characteristics Based on FEKO*

- M. Sun, S. Liu and L. Guo, *Research of Vortex Electromagnetic Beam Generation and Scattering Characteristics Based on FEKO*, 2021 13th International Symposium on Antennas, Propagation and EM Theory (ISAPE), Zhuhai, China, 2021, pp. 1-3, doi: 10.1109/ISAPE54070.2021.9753414.
- li, Quan & Wu, Chao & Zhang, Zhihui & Song, Zhao & Zhong, Bin & Li, Song & Li, Hongqiang & Jin, Lijun. (2022). *High-Purity Multi-Mode Vortex Beam Generation With Full Complex-Amplitude-Controllable Metasurface*. IEEE Transactions on Antennas and Propagation. PP. 1-1. 10.1109/TAP.2022.3217192.
- A Papathanasopoulos, Y Rahmat-Samii, *A Review on Orbital Angular Momentum (OAM) Beams: Fundamental Concepts, Potential Applications, and Perspectives*, URSI GASS 2021

www.darpa.mil