Disruption Opportunity
DARPA-PA-24-04-04
Emon

I. Opportunity Description

The Defense Advanced Research Projects Agency (DARPA) Defense Sciences Office (DSO) is issuing a Disruption Opportunity (DO), inviting submissions of innovative basic or applied research concepts in the technical domain of radar waveform generation, electromagnetic (EM) wave propagation, and processing. This DO is issued under the Program Announcement for Disruptioneering, DARPA-PA-24-04. All awards will be made in the form of an Other Transaction (OT) for Prototype project. The total award value is limited to $2,000,000. This total award value includes Government funding and performer cost share if required or proposed.

To view the original DARPA Program Announcement (PA) for Disruptioneering, visit SAM.gov under solicitation number DARPA-PA-24-04:
https://sam.gov/opp/cb7a935d59bb4ceeb62b9515f7d9f9b0/view

A. Introduction

While the technical sophistication of radar systems has advanced tremendously since their inception, specifically with the use of digital circuitry that enables fine-tuned control over both waveform generation and received signal processing, the basic principles upon which radar operates have not varied greatly. However, some properties of the classical EM field have not yet been exploited fully, perhaps because of past limitations in sensor capabilities or lack of insight into the possible benefits of exploiting the more subtle aspects of the EM field. The intent of this DO is to explore these more subtle aspects that are enabled by the use of multiple Laguerre-Gauss beam, orbital angular momentum, Hankel prolate beams, and other advanced radar operating techniques.

One of these underutilized properties is the fact that the EM field is a spatiotemporally varying three-dimensional (magnetic or electric) vector field, i.e., it has a *tensorial* nature. Radar systems typically transmit waveforms possessing planar phase fronts and thus cannot extract some potentially available information. By creating and then receiving the spatial components of the field vector after its interaction with the environment, one can extract information contained in its time-varying magnitude and direction. Conversely, most conventional radar systems use antennas spanning one or two spatial dimensions with single polarization elements and with planar wavefront operation do not utilize the tensor nature of EM fields.

Interrogating an environment with a signal that offers more degrees of freedom in which interaction phenomena can be encoded should enable us to extract not only more information, but more *salient* information.

B. Objective/Technical Scope

The objective of the Emon program is to investigate the potential utility of constructing radar systems that benefit more completely from the tensorial nature of the EM field. We are particularly interested in looking at waveforms with *spatially varying phase fronts.* Note that solutions to the wave equation of the form $\varphi(x,t) = \psi(k \cdot x - ct)$, which are the traditional building blocks of transmitted radar waveforms, must result in waves with characteristic planar surfaces, i.e., those where the field (or its associated potential) is constant across a plane. However, there are many solutions to the Helmholtz equation that do not yield planar phase fronts. In optics, researchers have studied alternatives such as Orbital Angular Momentum (OAM) states, Laguerre-Gaussian and Hermite-Gaussian beams, and beams based on prolate-spheroidal harmonics. Each class of solution possesses unique characteristics that can be used depending on circumstance and desired application.

Because radar is an active sensing modality that relies on the reception and subsequent processing of *reflected* signals, one must also characterize the expected interaction phenomenology of the target scene with nonstandard waveforms. This is the crux of the problem: though a fully tensorial EM field can both probe and therefore capture previously unobservable aspects of its environment, it is only valuable if we can extract and subsequently exploit this information. Therefore, we must not only produce novel waveforms, but also recognize their probative value, both qualitatively and, eventually, quantitatively.

Proposers should describe in their technical proposal how the program metrics shown in Table 1 will be met. These metrics are some of the potential gains being reported in recent literature in this area [1-7] that could be impacting radar systems. Proposers shall indicate the approach to performing proof-of-concept laboratory experiments. For example, the proposer might leverage low-cost multi-channel automotive radar technologies or coherent systems built on Wi-Fi technologies. The theoretical goals listed assume either a monostatic configuration or a pseudo-monostatic configuration when the same aperture is not used to transmit and receive. Larger baselines used to observe the target scene via wide-baseline bistatic scattering-induced changes in radar cross-section beyond the change in phase due to aperture position is not of interest. This restriction is intended to limit the aperture extent, D, in Table 1.

Proposers are encouraged to describe their own metrics that they deem critical for their approach. Proposers should provide justification for why the proposed performance thresholds for these metrics will provide confidence in the approach's ability to scale and outperform current state-of-the-art methods.

Table 1. Emon Metrics

Parameter	Program Goal
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

C. Structure

Proposals submitted in response to this DO must be unclassified and encompass a single project phase comprising two primary areas of interest. The first focuses on theoretical/analytic investigations into the efficacy of radar based on nontraditional waveforms, with the expectations that optical regime results may be extended to RF. The second deals with experimental verification of theoretical predictions, including design and execution of relevant experiments.

While a notional timeline appears below (**Error! Reference source not found.**), proposers are free to allocate time and resources as they see fit, as long as program milestones (as outlined in Schedule/Milestones) are met in a timely fashion. Combined theoretical and experimental efforts for this DO should not exceed 18 months. The total award value is limited to $2,000,000, which includes Government funding and performer cost share, if required or if proposed.

Both areas may generate information subject to Controlled Unclassified Information (CUI) controls. Proposers should review DARPAPA-24-04 Section 8.2.2 regarding Department of Defense requirements related to protection of CUI and Controlled Technical Information (CTI). A CUI Guide will be provided to proposers who are selected for an award.

D. Primary Area of Interest Descriptions

I. Theoretical/Analytical Development – The theoretical framework for tensor fields is better developed for optical systems [8-10] than it is for radar, where different aspects of the physics are important; we must be able to predict both the near and far fields that emerge with specified inputs and the return fields from targets in the scene. These predictions should be based on both analytic and computational methods. Because such predictions are by design novel, existing EM analysis software (e.g., Ansys HFSS, Altair FEKO, COMSOL multi-physics) may be inadequate and need to be augmented.

Radar performance is typically quantified using specifications such as minimum resolution, radar cross section (RCS), beamwidth, gain, efficiency, track metrics, etc. This allows engineers to design and explain performance requirements without needing to understand or explain the nuances of the physics. Similar quantification is needed for Emon.

Selected teams will be expected to predict, calculate, and eventually measure radar performance when interrogating a variety of "standard" targets: flat plate, sphere, cone, etc. Proposers should indicate development for a minimum of three of the canonical shapes in the footnote to Table 1.

Note also that phase change across the target is important, and the available phase change is determined by the aperture extent as well as the target size. Consequently, proposers must also consider both the aperture extent and the target size in theoretical development as well as in their design of subsequent experiments. (See below.)

Nonstandard wave field interactions with the target scene will require signal processing techniques to extract information from the received scene. Proposers will include the development of the signal processing necessary to take advantage of tensor fields in their planned development.

II. Experimental Validation – Predictions made via theoretical analyses and/or computational simulation will be verified experimentally. Performers must design and implement a testbed that will enable validation of their conjectured results.

As novel radar waveforms exploit nonstandard physical phenomenology, commercial radar transmit and receive components may need to be modified or redesigned. It is expected that teams will leverage advances in both available hardware and software-defined radio/radar (SDR). Taking full advantage of the latter will almost certainly require software or radar control innovation. For example, the emergence of low-cost automotive radar could provide a readily extensible platform enabling the demonstration of how extending the current radar approach could have significant benefit and utility.

While sub-scale laboratory experiments initially confirm theoretical predictions, systems must exhibit operational realism. Teams must therefore evaluate performance in the more complex environments where radar systems are typically deployed to identify not only technological benefits but also potential confounding factors. These more complex environments could include distributed clutter and target motion within the tensor field.

E. Schedule/Milestones – A program schedule is illustrated in Figure 1.

Proposers must address the following fixed payable milestones in their proposals. Proposers must complete the "Schedule of Milestones and Payments" Excel Attachment provided with this DO to submit a complete proposal and fulfill the requirements under Volume 2, Price Volume. If selected for award negotiation, the fixed payable milestones provided will be directly incorporated into Attachment 3 of the OT agreement ("Schedule of Milestones and Payments"). Proposers must use the Task Description Document template provided with the Program Announcement DARPA-PA-24-04, which will be Attachment 1 of the OT agreement.

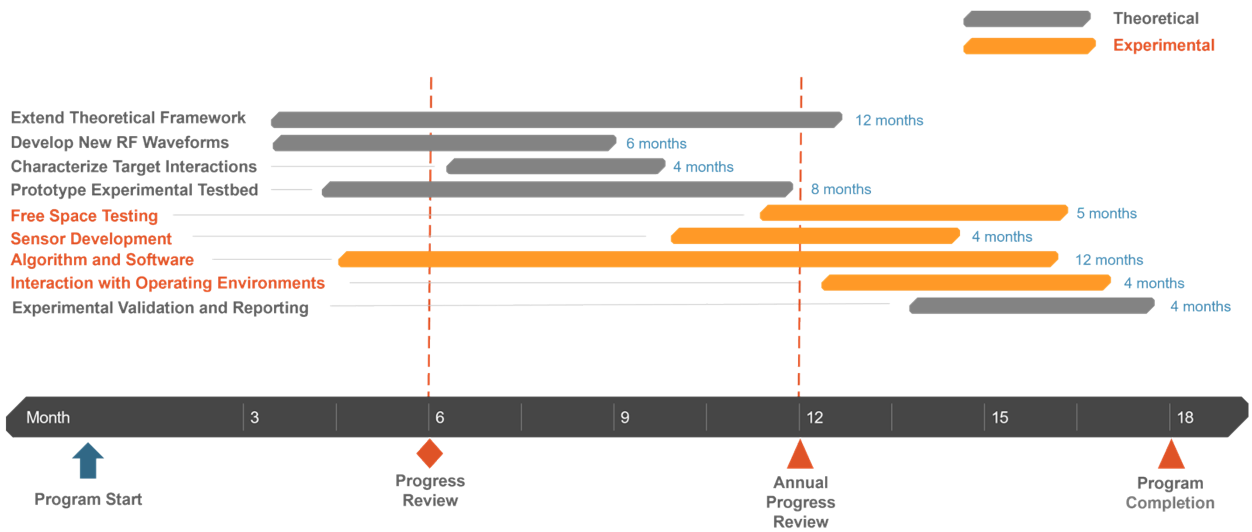

Figure 1 - Emon Notional Project Timeline

Program fixed milestones for this program must include, at a minimum, the following:

- Month 1: Project Kick-off Meeting
  - Submit milestone report detailing kick-off meeting
    - All supporting positions identified in the proposal are assigned to personnel, and names are provided to the Government
- Months 2-4: Develop initial experimental validation test plans and test bed
  - Milestone report and/or PowerPoint presentation describing the following:
    - Confirm all proposed personnel working on the project at the planned level of effort.
    - Creation of theoretical/analytic framework
    - Initial waveform development and environment/target interaction

    - explorations
    - Initial plans for experimental validation testing and testbed
- Months 5-6: Finalize waveform development approach and initial waveform set
  - Milestone report and/or PowerPoint presentation describing the following:
    - Status on ability to characterize target interactions, i.e., theoretically predicting characteristics of reflections
    - Describe expected processing approach for tensor waveform fields
    - Risk reduction activities for experimental testbed development complete and risks resolved
- Months 7-9: Final Designs for Prototype Experimental Testbed
  - Milestone report and PowerPoint presentation outlining the following:
    - Confirm completion of all initial analytic analyses
    - Status of implementation of initial processing approach to tensor waveform fields
    - Detail final design(s) for prototype experimental testbed and testing
- Months 10-12: Reporting on free space testing, transmission and sensing
  - Milestone Report and live demonstration highlighting:
    - Initial free space testing results
    - Sensor development and refinement plans
    - Status of ability to transmit, receive and process tensor wavefields
- Months 13-15: Prototype system finalization
  - Milestone Report and live demonstrations emphasizing:
    - Algorithm and software refinement, including explanation of limitations and processing opportunities provided
    - Results of end-to-end testing, focusing on computation of radar parameters in diverse operating environments
- Months 16-18: Program Completion
  - Milestone Report, PowerPoint Presentation, delivery of hardware and software; reporting must feature
    - Experimental data collection, analysis, and validation of theory
    - Reporting and recommendations for future research

For planning and budgetary purposes, proposers should assume a program start date of March 24, 2025. Schedules will be synchronized across performers, as required, and monitored/revised as necessary throughout the program's period of performance.
All proposals must include the following meetings and travel in the proposed schedule and costs:

- Regular teleconference meetings will be scheduled with the Government team for progress reporting and problem identification and mitigation. Notionally, these will be scheduled as a Teams call every other week.
- There will be quarterly reviews to be accompanied by progress reports, with an Annual Review after month 12.
- Proposers should anticipate two site visits by the DARPA Program Manager, during which the selected performers will have the opportunity to demonstrate progress toward agreed-upon milestones.
- To foster collaboration between teams and disseminate program developments, a two-day

virtual/hybrid Principal Investigator (PI) meeting will be held approximately every six months. At least one of these will be aligned with a suitable conference such as the Asilomar Conference on Signals, Systems and Computers, where foundational work in tensor-related sensors is now occurring.

A. Deliverables

Performers will be expected to provide, at a minimum, the following deliverables:

- Status update material for regular teleconferences in contractor format. The format may be PowerPoint viewgraph format. Annotation in the notes section is encouraged when there is significant technical background or details.
- Presentation material for reviews described above.
- Publications and/or technical reports generated for this program
- Experimental test plans that include radio frequency radiation personnel safety
- Experimental test data.
- Delivery of test targets and test systems developed under this DO is negotiable

II. Award Information

Selected proposals that are successfully negotiated will result in the award of an OT for Prototype project. See Section 4 of DARPA-PA-24-04 for information on awards that may result from proposals submitted in response to this announcement.

Proposers must review the model OT for Prototype agreement provided as an attachment to DARPA-PA-24-04 prior to submitting a proposal. DARPA has provided the model OT to expedite the negotiation and award process and ensure DARPA achieves the goal of Disruptioneering, which is to enable DARPA to initiate a new investment in less than 120 calendar days from idea inception. The model OT is representative of the terms and conditions that DARPA intends to include in all DO awards. The task description document, schedule of milestones and payments, and data rights assertions requested under Volumes 1, 2, and 3 will be included as attachments to the OT agreement upon negotiation and award.

Proposers may suggest edits to the model OT for consideration by DARPA and provide a copy of the model OT with track changes as part of their proposal package. DARPA may not accept suggested edits. The Government reserves the right to remove a proposal from award consideration should the parties fail to reach an agreement on OT award terms and conditions. If edits to the model OT are not provided as part of the proposal package, DARPA assumes that the proposer has reviewed and accepted the award terms and conditions to which they may have to adhere and the model OT agreement provided as an attachment, indicating agreement (in principle) with the listed terms and conditions applicable to the specific award instrument.

To ensure that DARPA achieves the Disruptioneering goal of an award within 118 calendar days from the posting date (November 27, 2024) of this announcement, DARPA reserves the right to cease negotiations when an award is not executed by both parties (DARPA and the selected organization) on or before March 24, 2025.

III. Eligibility

See Section 7 of DARPA-PA-24-04 for information on who may be eligible to respond to this announcement.

IV. Disruption Opportunity Responses

A. Proposal Content and Format

All proposals submitted in response to this announcement must comply with the content and format instructions in Section 5 of DARPA-PA-24-04. All proposals must use the templates provided as Attachments to DARPA-PA-24-04 and the "Schedule of Milestones and Payments" Excel Attachment provided with this DO and follow the instructions therein.

Information not explicitly requested in DARPA-PA-24-04, its Attachments, or this announcement may or may not be evaluated at DARPA's discretion.

B. Proposal Submission Instructions

Responses to DARPA-PA-24-04-04 shall be submitted electronically to DARPA's Broad Agency Announcement (BAA) Portal (https://baa.darpa.mil).

DARPA will acknowledge receipt of complete submissions via email and assign identifying numbers that should be used in all further correspondence regarding those submissions. If no confirmation is received within two (2) business days, please contact emon@darpa.mil to verify receipt.

When planning a response to this DO, proposers should take into account the submission time zone and that some parts of the submission process may take from one (1) business day to one month to complete (e.g., registering for a SAM Unique Entity ID (UEI) number or Tax Identification Number (TIN)).

Electronic Upload

First-time users of the DARPA BAA Portal must complete a two-step account creation process. The first step consists of registering for an extranet account by going to the URL above and selecting the "Account Request" link. Upon completion of the online form, proposers will receive two separate emails; one will contain a username, and the second will provide a temporary password. Once both emails have been received, the second step requires proposers to go back to the submission website and log in using that username and password. After accessing the extranet, proposers may then create a user account for the DARPA Submission website by selecting the "Register your Organization" link at the top of the page. Once the user account is created, proposers will be able to see a list of solicitations open for submissions, view submission instructions, and upload/finalize their proposal.

Proposers who already have an account on the DARPA BAA Portal may log in at https://baa.darpa.mil, select this solicitation from the list of open DARPA solicitations and proceed with their proposal submission. Note: proposers who have created a DARPA Submission website account to submit to another DARPA Technical Office's solicitations do not need to create a new account to submit to this solicitation.

All full proposals submitted electronically through the DARPA Submission website must meet the following requirements: (1) uploaded as a zip file (.zip or .zipx extension); (2) only contain the document(s) requested herein; (3) only contain unclassified information; and (4) must not exceed 100 MB in size. Only one zip file will be accepted per full proposal. The DARPA Submission website will reject full proposals not uploaded as zip files. Technical support for the DARPA Submission website is available during regular business hours, Monday – Friday, 9:00

a.m. – 5:00 p.m. Requests for technical support must be emailed to BAAT_Support@darpa.mil with a copy to emon@darpa.mil. Questions regarding submission contents, format, deadlines, etc., should be emailed to emon@darpa.mil. Questions/requests for support sent to any other email address may result in delayed/no response.

Since proposers may encounter heavy traffic on the web server, DARPA discourages waiting until the day proposals are due to request an account and/or upload the submission. Note: Proposers submitting a proposal via the DARPA Submission site MUST (1) click the "Finalize" button for the submission to upload AND (2) do so with sufficient time for the upload to complete prior to the deadline. Failure to do so will result in a late submission.

C. Proposal Due Date and Time

Proposals in response to this announcement are due no later than 4:00 p.m. on January 24, 2025. As described in Section 5 of DARPA-PA-24-04, full proposal packages must be submitted per the instructions outlined in this DO *and received by DARPA* no later than the above time and date. Proposals received after this time and date may or may not be reviewed at DARPA's discretion.

Proposers are warned that the proposal deadline outlined herein is in Eastern Time and will be strictly enforced. When planning a response to this announcement, proposers should consider that some parts of the submission process may take from one (1) business day to one (1) month to complete.

V. Proposal Evaluation and Selection

Proposals will be evaluated and selected in accordance with Section 6 of DARPA-PA-24-04. Proposers will be notified of the results of this process as described in Section 8.1 of DARPA-PA-24-04.

VI. Administrative and National Policy Requirements

Section 8.2 of DARPA-PA-24-04 provides information on Administrative and National Policy Requirements that may be applicable for proposal submission and performance under an award.

VII. Point of Contact Information

Dr. Frank Robey, Program Manager, DARPA/DSO, emon@darpa.mil

VIII. Frequently Asked Questions (FAQs)

All technical, contractual, and administrative questions regarding this announcement must be emailed to emon@darpa.mil. Emails sent directly to the Program Manager or any other address may result in delayed or no response.

All questions must be in English and must include the name, email address, and telephone number of a point of contact. DARPA will attempt to answer questions publicly in a timely manner; however, questions submitted within seven (7) calendar days of the proposal due date listed herein may not be answered.

DARPA will post an FAQ list under the DO on the DARPA/DSO Opportunities page at (http://www.darpa.mil/work-with-us/opportunities). The list will be updated on an ongoing basis until one (1) week before the proposal due date.

For those new to DARPA or national security, DARPA makes available a free, comprehensive resource via DARPAConnect on how to do business with the agency. In addition to DARPA 101 materials, relevant preparatory modules includes "Understanding DARPA Broad Agency Announcements." Registration and access are free at www.darpaconnect.us.

IX. References

1. S Mohammadi, et.al., Orbital angular momentum in radio—A system study, IEEE transactions on Antennas and Propagation, Feb 2010.
2. B. Thide´, et.al., Utilization of Photon Orbital Angular Momentum in the Low-Frequency Radio Domain, Phys Rev Letters, 2007.
3. C. Zhang, D. Chen, X. Jiang, RCS Diversity of Electromagnetic Wave Carrying Orbital Angular Momentum, Nature Reports, 2017.
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5. Zhang, et.al.; Analysis of electromagnetic scattering from typical targets for orbital-angular-momentum waves: Theoretical model, IET, 2022
6. K. Liu, Y. Gao, X. Li, Y. Cheng, Target scattering characteristics for OAM-based radar. AIP Advances 1 February 2018; 8 (2): 025002. https://doi.org/10.1063/1.5018833
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8. 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.
9. A Papathanasopoulos, Y Rahmat-Samii, A Review on Orbital Angular Momentum (OAM) Beams: Fundamental Concepts, Potential Applications, and Perspectives, URSI GASS 2021
10. A. E. Willner, H. Huang, Y. Yan, Y. Ren, N. Ahmed, G. Xie, C. Bao, L. Li, Y. Cao, Z. Zhao et al., "Optical communications using orbital angular momentum beams," Advances in Optics and Photonics, vol. 7, no. 1, pp. 66–106, 2015.