2023 Positioning, Navigation, and Timing (PNT) Focused Solicitation

Request for Proposals (RFP)

Issued: October 26, 2023

White Paper Responses Due Date: November 28, 2023 at 5:00 pm PDT

Full Proposals Due Date: January 26, 2024 at 5:00 pm, PDT

Award Notifications: March 7, 2024

1. Mission/Objectives

This solicitation is issued by SEMI, a trade association representing the microelectronics manufacturing industry. It will be conducted and managed by the MEMS & Sensors Industry Group (MSIG), a Technology Community under SEMI. Funds distributed by SEMI are provided by the U.S. Government through DEVCOM Army Research Laboratory (ARL) for this purpose.

This solicitation's objective is to advance positioning, navigation, and timing (PNT) solutions that determine the position of mobile and stationary assets and provide the ability to navigate under critically important situations. Global Positioning System (GPS) signals generally provide this information in real time. GPS signals may be obstructed for many reasons, including but not limited to: 1) The satellite signal is jammed or spoofed; 2) the signal transmission is obstructed by large objects like buildings; and 3) GPS coverage may be limited by geographical considerations.

When a GPS signal is lost, current solutions in the marketplace use inertial measurement units (IMUs) to maintain positioning accuracy. Over time, however, accumulated errors make position determination unreliable. The GPS signal, when it is received again, can be used to reset IMU error so that if the GPS signal is lost again, navigation and location are maintained subsequently.

Through this solicitation SEMI brings together ARL and the MSIG consortium in a unique public-private partnership to address common challenges, innovate, and accelerate business and technical results. MEMS and sensors currently play an integral role in billions of electronic devices and have more recently been developed towards advancing next-generation PNT capabilities in small form factors.

SEMI MSIG members bring a fresh perspective to PNT solutions by utilizing the experience of subject matter experts in the field of commercial navigation systems. The intent of the funded R&D program is to build on the Phase 1 SEMI MSIG PNT program started in 2020, continue the Phase 2 program started in 2022, and identify new areas and approaches to PNT solutions for GPS-denied environments. Emphasis will be placed on system solutions, including but not limited to software, sensor fusion, cost-effective process innovation, advanced packaging solutions, component innovations, and disruptive materials development. R&D may include software, hardware, and advanced packaging requirements of optical and MEMS-based positioning and timing systems that demonstrate improved bias stability and reduced sensor noise. The technical areas of interest will need to show viability to the total GPS-denied problem, meeting the system-level performance necessary to advance the state of the art.

The three thrust area topics in this 2023 solicitation are:

1. Novel Materials, Fabrication, Packaging, and Testing Techniques for Low-SWaP Inertial and PNT Sensors
2. Advanced Active and Passive Integrated Photonics for Low-SWaP Atomic Clocks, Quantum Systems, and PNT Sensors
3. Advancements Towards Low-SWaP-C, GPS-Free PNT Technologies

Additional details about each topic are listed in the section below titled "Focused Solicitation." Concept demonstrations and/or prototypes must be part of the deliverables for consideration of an award. Demonstrations and partnerships with end-user communities for independent test and characterization are highly encouraged. End-users can be defined as defense customers, commercial market segment customers, or, in some cases, the direct supply chain customer. When possible, prototypes should be delivered to ARL and/or SEMI.

2. Proposal Process and Topics

The proposal process will start with a white paper submission. Members of the **MSIG RFP Review Committee** comprised of the MSIG PNT technical advisory council (TAC), the MSIG PNT governing council (GC), and US government subject matter experts (SME's), will review and rank the white papers and recommend the higher ranked white papers for full proposal submission.

Here is the current list of MSIG PNT TAC and GC companies:

1. SoftMEMS
2. Teledyne
3. GE Research
4. Analog Devices
5. NXP
6. PNI Sensor
7. Northrup Grumman

White papers and full proposals will be evaluated by the MSIG RFP review committee based on a set of criteria that include: budget; collaboration value; dual-use (commercial and military) applicability; relevance to the ecosystem; relevance to advancing or demonstrating lower size, weight, power, and cost PNT solutions; schedule and milestones; deliverables; team diversity; and overall proposal quality. White paper and full proposal content requirements are listed in sections 6 and 7. Typical project phases run from 9 – 18 months including a final report. Multi-phase projects can be proposed as described below. Note, if you are awarded funding, representatives of the MSIG TAC and GC companies will be invited to the online quarterly reviews. Note, they will not have access to your technical or financial quarterly reports which are a reporting requirement to the U.S. government and SEMI as the U.S. government contract holder.

In soliciting these proposals, MSIG plans to grant and administer funding which should be matched (minimum match of 50% of total project cost required) with funds in the form of monetary and in-kind contributions provided by the grant recipients to cover the total project cost. If all other criteria are equal, preference will be given to proposals with a higher percentage of cost share. It should be noted that historically, the cost share for SEMI's PNT funded development programs has averaged 58% industry funding. Project Teams of 4 to 8 skilled technical resources from MSIG member companies and the Department of Defense will be identified to provide project oversight and direction.

In responding to this solicitation, partnering among industrial companies and/or R&D organizations, and/or university teams is appropriate and is highly encouraged. Individual responses are appropriate where size, breadth and expertise are sufficient to effectively cover all areas (e.g., technical resources, financial stability, and market presence) critical to the successful completion of the proposal. All proposals must include at least one for-profit organization.

MSIG will support technical approaches that are novel or game-changing, thus having a more significant element of risk, as well as approaches that represent evolutionary improvements upon existing capability, which tend to be less risky and involve shorter development and delivery intervals. It is recognized that it may be desirable to include information that is considered confidential and proprietary by the submitter to convey the technical merits of the proposal fully and effectively. While a best effort will be made to restrict the proposal information to those with a need to know expressly for purposes of the review, it is recommended that the inclusion of proprietary information be limited to the minimum necessary to convey the highlights of the technical approach.

With respect to intellectual property developed under a SEMI contract, the following policy has been established to encourage project teams to cooperate with SEMI and our government partners in the accomplishment of their objectives:

> "Legal title to any technology developed under a SEMI funded research and development contract will be the property of the development partner."

To foster collaboration within the consortium and for the duration of the participant's membership in the consortium, development partners will enable intellectual property evaluation by other development partners, solely internally, and subject to the provisions of confidentiality and devoid of conflict of interest.

SEMI recognizes that diversity, equity and inclusion (DEI) and industry awareness are key items to advance the PNT ecosystem. This consortium-based funding requires participants to operationalize DEI policies and conduct industry awareness activities such as a short promotional video targeting high school students.

Development agreements generally will be awarded on an actual cost basis, not-to exceed contracts, with payments to be made quarterly and based on milestones as presented in the proposal. Institution U.S. government approved rate structure should be used. If not available, the normal commercial cost accounting system used for internal R&D projects will be acceptable. The methods used to value "cost sharing" cost must be the same as those used to value the full project costs. All suppliers are expected to have a government approved or industry standard accounting system by which actual project costs are tracked and reported. This is an absolute requirement to be sure that cost share obligations are met.

A work breakdown structure should be the basis of project schedules, milestone definitions, and cost estimates. Cost estimates for each major step leading to completion of a milestone should be used as the basis for the amount from the grant to be paid. A spreadsheet showing these calculations should accompany each proposal. The same spreadsheet should also show the specifics of how you will contribute your matching share of the total costs, or "cost share," of the development contract. SEMI funds cannot be used to purchase capital equipment, so any capital equipment purchases need to come from the cost share. Cost sharing expectations have been established in the master agreement between SEMI and ARL, and a minimum 50/50 cost sharing ratio between government and industry is required.

3. Research and Development Award Budget

Individual awards for this 2023 RFP solicitation are projected to be in the budget range of $200K - $750K with an additional matching (or greater) cost share from the award recipient bringing the total investment per project to approximately $400K - $1.5M. Depending on responses, 7 – 10 awards may be made, but

SEMI reserves the right to make no awards. Proposals may be from single institutions or a project team comprising various companies and/or universities but must include at least one for-profit institution. Proposals from multi-institutional teams are preferred.

Multi-phase project proposals can be submitted with subsequent phases being considered as unfunded options. Unfunded options are not guaranteed and may be approved by the MSIG PNT Review Committee and ARL during the first phase without the need to write another full proposal. The committee might request a modified statement of work of unfunded options based on results and feedback from the first phase. Unfunded options should be in the same budget range mentioned above, namely $200-$750K per project phase. The same cost share (at least 50%) rules apply to multi-phase proposals.

4. TRL and MRL Entry and Exit Levels

The maturity of the proposed research effort should be assessed by a TRL or MRL definition. We seek innovations targeting TRL/MRL 2 through 5 and showing clear technology maturation over the duration of the project. TRL and MRL are determined through the project team self-assessment as well as ARL or other designated end user assessment. Proposers should consider TRL and MRL definitions and reference specific elements within the TRL category that will enable technology maturation. The RFP review committee will primarily focus on justification and maturation of TRL; however, reference to MRL awareness should be included.

TRL and MRL definitions are described below:

TECHNOLOGY READINESS LEVEL DEFINITIONS

TRL 2. Technology concept and/or application formulated

- Invention begins
- Once basic principles are observed, practical applications can be invented
- Applications are speculative and there may be no proof or detailed analysis to support the assumptions
- Examples are limited to analytic studies

TRL 3. Analytical and experimental critical function and/or characteristic proof of concept

- Active R&D is initiated (beyond basic principle observation)
- Includes analytical studies and laboratory studies to physically validate analytical predictions of separate technology elements
- Examples include components that are not yet integrated or representative

TRL 4. Component and/or breadboard **validation** in laboratory environment

- Basic technological components are integrated to establish that they will work together
- Relatively "low fidelity" compared with the eventual system
- Examples include integration of "ad hoc" hardware in the laboratory

TRL 5. Component and/or breadboard **validation** in relevant environment

- Fidelity of breadboard technology increases significantly
- Basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment
- Examples include "high-fidelity" laboratory integration of components

MANUFACTURING READINESS LEVEL DEFINITIONS

MRL 2. Identification of manufacturing concepts

- identification and broad-based studies that address analysis of material and process approaches, material effects and availability, potential supply chains, needed workforce skillsets, potential future investments
- Manufacturing and quality potential future requirements are identified and analyzed
- An understanding of manufacturing feasibility and risk is emerging.

<u>MRL 3. Manufacturing proof of concept developed</u>

- Conduct analytical or laboratory experiments to validate paper studies
- Experimental hardware or processes have been created but are not yet integrated or representative
- Materials and/or processes have been characterized for manufacturability and availability, but further evaluation and demonstration is required

<u>MRL 4. Capability to produce the technology in a laboratory environment</u>

- Required investments, such as manufacturing technology development identified.
- Processes to ensure manufacturability, producibility and quality are in place to produce demos.
- Manufacturing risks identified for prototype build.
- Manufacturing cost drivers identified.
- Producibility assessments of design concepts have been completed.
- Key Performance Parameters (KPP) identified.
- Special needs identified for tooling, facilities, material handling and skills.

<u>MRL 5. Capability to produce prototype components in a production relevant environment</u>

- Manufacturing strategy refined and integrated with Risk Management Plan.
- Identification of enabling/critical technologies and components is complete.
- Prototype materials, tooling and test equipment demonstrated on components in a production relevant environment.
- Manufacturing technology development efforts initiated or ongoing.
- Producibility assessments of key technologies and components ongoing.
- Cost model based upon detailed end-to-end value stream map

TRL/MRL CLARIFYING DEFINITIONS

<u>BREADBOARD</u>: Integrated components that provide a representation of a system/subsystem and which can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.

<u>HIGH FIDELITY</u>: Addresses form, fit and function. High fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.

<u>LOW FIDELITY</u>: A representative of the component or system that has limited ability to provide anything but first order information about the end product. Low fidelity assessments are used to provide trend analysis.

<u>MODEL</u>: A reduced scale, functional form of a system, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

<u>OPERATIONAL ENVIRONMENT</u>: Environment that addresses all the operational requirements and specifications required of the final system to include platform/packaging.

PROTOTYPE: The first early representation of the system which offers the expected functionality and performance expected of the final implementation. Prototypes will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

RELEVANT ENVIRONMENT: Testing environment that simulates the key aspects of the operational environment.

SIMULATED OPERATIONAL ENVIRONMENT: Environment that can simulate all the operational requirements and specifications required of the final system or a simulated environment that allows for testing of a virtual prototype to determine whether it meets the operational requirements and specifications of the final system.

PRODUCTION RELEVANT ENVIRONMENT: An environment normally found during MRL 5 and 6 that contains key elements of production realism not normally found in the laboratory environment (e.g. uses production personnel, materials or equipment or tooling, or process steps, or work instructions, stated cycle time, etc.). May occur in a laboratory or model shop if key elements or production realism are added.

Additional Information on the Technology and Manufacturing Readiness Assessment process can be found using these links:

TRL Assessment: https://api.army.mil/e2/c/downloads/404585.pdf
MRL Assessment: http://dodmrl.com

5. Focused Solicitation

In recent decades, both the U.S. military and civilians have relied on global positioning system (GPS) satellites to provide accurate PNT data. However, GPS is not always available and is vulnerable to jamming and spoofing. ARL has been investigating and developing technologies that enable low size, weight, power, and cost (SWaP-C) PNT solutions for operation in GPS-contested or –denied environments. To achieve these ends, the three-proposal thrust-area topics are described below:

1. Novel Materials, Fabrication, Packaging, and Testing Techniques for Low-SWaP-C Inertial and PNT Sensors

The purpose of this solicitation is to fund a recipient, a single team, or multiple recipients and teams to conduct an R&D effort to develop and demonstrate novel microfabrication process modules to enable low-SWaP-C inertial and PNT sensors.

Beginning in the 1990s, the DoD invested in developing MEMS technology that was initially adapted from standard semiconductor microfabrication techniques and expanded to accommodate novel materials and mechanical structures. As processing capabilities advanced, the research community and industry developed various practical MEMS devices such as gyroscopes and accelerometers for tracking, stabilization, and high-*g* sensing. Recent basic research programs have explored alternative inertial sensing modalities (including photonic and MEMS-photonic integration, as well as novel architectures and material systems) for inertial navigation in long-duration missions and deployment in extreme environments. Most inertial technologies that enable high-performance navigation have high SWaP-C and cannot be used in consumer handheld devices nor portable DoD platforms. The goal of this solicitation is to engage the manufacturing supply chain and facilitate industry transition of candidate architectures and approaches that have demonstrated high-performance inertial sensing.

Potential areas of interest include:

- Lower cost, lower power, and more universal testing kit (e.g. lower SWaP-C or chip-scale locking amplifiers or other test equipment)
- Broadly accessible state-of-the-art testing facility and service
- Techniques and process equipment for *in situ* surface oxide removal and deposition of anti-stiction and anti-dielectric-charging coatings for MEMS PNT devices
- High-aspect-ratio etching ("Bosch"-like) processes for silicon carbide (SiC) and fused quartz inertial sensors;
- High-Q, low-loss piezoelectric materials (e.g. AlN, PZT) compatible with silicon inertial sensor production processes; high-Q, low-loss piezoelectric composites and electrode materials;
- Atomic layer deposition/etching to enhance PNT sensor performance;
- Wafer-level vacuum packaging for rapid PNT sensor prototyping and enhanced performance
- Heterogeneous integration of photonic components (i.e. multi-chip photonic modules);
- Through-package photonic interconnects.

Proposer teams could include sensor designers and manufacturers, equipment manufacturers, universities, and industry participants.

2. Advanced Active and Passive Integrated Photonics for Low-SWaP Atomic Clocks, Quantum Systems, and PNT Sensors

The purpose of this solicitation is to fund a recipient, a single team, or multiple recipients and teams to conduct an R&D effort to develop and demonstrate advanced active and passive integrated photonic systems compatible with low-SWaP, atomic clocks, quantum systems, and PNT sensors. Note that atomic clocks, quantum systems, and PNT sensor developments that do not necessarily include integrated photonics should fall into thrust area 3 described in the next section.

Following the success of the vapor-cell chip-scale atomic clock (CSAC), the DoD has funded efforts to realize the next generation of miniaturized atomic clocks for improved navigation and timing, communications, and sensing applications. Clock physics approaches such as laser cooling and ion trapping have demonstrated improved stability in the laboratory. However, laboratory systems are complex and highly susceptible to environmental perturbations. To miniaturize these clocks into a deployable form factor and operate them in realistic environments, enabling component technology for such systems requires further development, particularly with the laser sources needed to cool, trap, and manipulate atoms.

In addition to the technical difficulties of realizing chip-scale lasers for atomic systems, the lack of US-based foundry services for integrated photonics in compound semiconductor materials systems (GaAs, GaN, AlN, etc.) poses a challenge to enable volume production of future atomic clocks and PNT sensors.

Theory and modeling, material growth and characterization, laser fabrication, system design, and manufacturability should be considered for the following areas of interest:

- Two lasers with different wavelengths on the same PIC chip, which are suitable for atomic spectroscopy / clock measurements
- Improved manufacturability of passive PICs that can support two dissimilar wavelengths
- High quality photonic wire bonding capability
- Heterogenous integration of dissimilar active material/devices on the same PIC
- Low-SWaP, narrow-linewidth lasers for microwave and optical atomic clocks
- Active/passive photonic integrated circuits (PICs) and PIC elements (including phase modulators, switches, detectors, isolators, etc) for cold atom clocks and inertial sensors

- Photonic and RF low-loss and low-noise interfaces, low-loss, on/off-chip, or PIC-to-PIC coupling techniques

Proposers are encouraged to team with clock and navigation sensor manufacturers to understand the necessary laser and photonic performance specifications (power, linewidth, efficiency) in context of the intended system.

3. Advancements Towards Low-SWaP, GPS-Free PNT Solutions

This topic invites proposals that build upon topics relevant to low-SWaP, GPS-free PNT. Lower cost is also of interest. Possible topics include, but are not limited to:

- Establishing PDKs and MPW runs for MEMS foundry operation
- Sensor fusion systems for resilient GPS-free PNT
  - The best visual odometry – inertial fusion approaches can maintain acceptable navigation accuracy only for minutes without being disciplined by GNSS. Introducing additional modalities (magnetometer, barometric, gravimetric, multi-IMU-array) can increase the useful life of such systems, but at the cost of high algorithmic complexity and brittleness to degraded performance in one or more sensors. This vulnerability defeats the purpose of leveraging multiple modalities with orthogonal failure modes. For this topic, we invite proposals to develop resilient multi-sensor fusion algorithms and systems, suitable for implementation on embedded hardware, which simultaneously exploit an ensemble of sensor modalities (greater than two) and can effectively cope with changes in individual sensor performance. Successful approaches will be able to maintain GPS-level accuracy for mission lives of at least 24 hours.
- Gravity sensors: technology that measures gravity at a level that would allow navigating with a gravity map
- Applying machine learning to navigation sensor/system calibration
  - While recent progress has improved MEMS manufacturing precision, complicated high-order cross coupling between axes, which varies from device to device, as well as over time and in response to environment, ultimately limits the performance of low-cost MEMS inertial sensors. To address this issue, neural networks may be employed at the component, device, or system level to produce optimal PNT solutions. This topic invites proposals that enhance current IMU capabilities and/or reduce time spent on calibration testing procedures with novel machine learning (ML)/artificial intelligence (AI) approaches.
- Ultra-low-SWaP oscillators targeting < 50 mW
  - In recent years, low-SWaP MEMS oscillators have taken over the low-end quartz market. Recent trends indicate that these devices will start to outperform low-end OCXOs with significantly reduced SWaP-C. This subsection is interested in the development of high-performance, low-g-sensitivity, vibration-insensitive or low-vibration-sensitivity, low-power, MEMS-based oscillators that could operate independently as a timing source or as the local oscillator for microwave atomic clocks.
- Novel inertial sensor designs
  - Color-center-based solid state sensors, such as nitrogen vacancy centers in diamond or silicon vacancy centers in SiC, have shown great promise in terms of potential performance. Transitioning these laboratory experiments towards low-SWaP devices will require improved growth, characterization, manufacturing studies, and systems engineering. This subsection looks to explore the design and demonstration of manufacturable solid-state sensors and improved sample growth.
- Photonic integrated circuits (PICs)

    - PICs have become standard devices in the telecom community. Some of the best available inertial sensors utilize light to detect and measure motion. Transitioning these cavity-based, or fiber optic-based systems to lower-SWaP-C, high-mechanical-Q material (e.g. fused silica) PIC platforms without performance degradation would greatly enhance capabilities. This subsection looks to explore the manufacturability and performance of PIC-based inertial sensors.
- Enabling technology for low-SWaP, integrated PNT systems
    - Successful transition of high-performance atomic technologies to practical deployed systems requires development of supporting components that can become part of the US manufacturing supply chain. This subsection looks to explore enabling technology for low-SWaP, integrated, high-performance, atom-based, PNT solutions.
- 5G/6G components and systems
    - The wide deployment of 5G technology could provide enhanced PNT capabilities. To better understand these capabilities, and build PNT systems that support 5G frequencies, will require significant investment from the industrial community. This subsection seeks to develop 5G components capable of operating throughout GPS-contested environments.

Proposer teams could include sensor designers and manufacturers, equipment manufacturers, universities, and industry participants.

6. Requirements for Receiving an Award

To submit a response to this RFP and subsequently be considered for an award, several requirements must be met as detailed below.

- To receive an award, the company or composite team of companies and universities must have a significant presence in the United States in the form of R&D activities and/or manufacturing. At least 50% of the work activity (funds) must be spent within the U.S. operations. The primary company leading the proposal must be a U.S.-owned company. Further, for the period of award performance plus the 3 years following, the primary company plus all IP resulting from said award must remain under control of a U.S.-owned or majority-controlled company. In certain cases, where it can be demonstrated that the development is both critical to U.S. manufacturing capability and unique, this "preference for U.S. operations" requirement can be waived with ARL approval. Any responding company requiring such a waiver must make this known in the pre-proposal document.

- The company or companies must be committed to volume manufacturing of the developed products and provision to the U.S. PNT industry on a right-of-first acceptance basis. Applied research conducted by universities will be considered and needs to meet this requirement by both partnering with a for-profit company and describing a pathway to commercialization and or licensing.

- The company or companies, including universities, must provide a matching share of the development cost in cash and in-kind contributions (e.g., labor and materials). A minimum of 50% cost share is required. It should be noted that historically, the cost share for SEMI's PNT funded development programs has averaged 58% industry funding.

- Companies and organizations that are selected for an award, including all partners and/or subcontractors, must subsequently join SEMI at the appropriate membership level. Membership information is available at https://www.semi.org/en/connect/semi-membership-levels

- Companies and organizations that are selected for an award, including all partners and/or subcontractors, must agree to terms and conditions set forth in the SEMI-MSIG Development Agreement before receiving any portion of the award.

7. White Paper Instructions

White paper submissions should be 5 pages (including any cover pages, tables of contents, figures, etc.) or less and contain a description of the proposed idea, high level budget, timeline, and background/experience of the R&D team. Follow-on project phases can be mentioned but don't need to be detailed until the full proposal. In addition, the submission should clearly outline the problem being addressed and how the proposed idea would solve the challenge. The current state of the art and the advancement over state of the art and its relevance to advancing or demonstrating PNT technology and solutions should be discussed. White paper submissions do not have to adhere to a specific format (other than maximum page length), but it may be useful to review the full proposal instructions in section 8 for suggested content.

White papers will only be accepted electronically up to 5:00 PM Pacific Time on the due date of November 22, 2023. Please submit your completed white paper or any questions via email to msig-rfp@semi.org. The top-rated white paper project teams will be asked to submit full proposals.

8. Full Proposal Instructions

The format below is provided to assist the reviewers' evaluations of responses and ensure that the major topic areas are covered. A full proposal is typically 20 pages with a page limit of 35 pages. Project phase durations range from 9-18 months.

Multi-phase project proposals can be submitted with subsequent phases being considered as unfunded options. Unfunded options are not guaranteed and may be approved by the MSIG PNT Review Committee and ARL during the first phase without the need to write another full proposal. The committee might ask for a modified statement of work of unfunded options based on results and feedback from the first phase. Unfunded options should be in the same budget range mentioned above, namely $200-$750K per project phase. The same cost share (at least 50%) rules apply to multi-phase proposals.

Content: The proposal shall comply with the following content and structure.

Page 1: Cover Page

Date
Project Title

Company Name
Address

Project Leader Contact Information (telephone and email)
Project Team (Prime & Subs, and team diversity information)
Project Duration

Total Project Cost
Cost Share
MSIG Funds Requested

Page 2: Table of Contents

Page 3: Executive Summary, containing a short description of the project objective and industry or supply chain impact

Pages 4-35: Proposal Content

1. Project Proposal
   1.1. Problem definition
   1.2. Project scope and objectives
   1.3. Technical approach, rationale and innovative claims with supporting data and diagrams
   1.4. Performance target metrics and/or specifications (competitive benchmark required)
   1.5. Prior work, current status, and results (if any)

2. Statement of Work
   2.1. Project management approach
      2.1.1. Roles and relationships of key personnel and institutions
      2.1.2. Lead institution and subcontract partners
   2.2. Project schedule
   2.3. Detailed task description
   2.4. Milestones and deliverables including:
      2.4.1. Mandatory: quarterly technical and financial reports, quarterly review presentations, final report, and industry awareness activities
      2.4.2. Other possible examples: process definition, PDKs, test results, software, demonstration prototypes, etc …

3. Detailed Project Cost and Cost Share by Task or by Quarter
   3.1. Labor, materials, overhead, and capital

4. Project Risk Assessment
   4.1. Table: Analysis of Risk and Mitigation Strategy (list risk assessment tools/processes used if any)

Risk	Consequence	Mitigation Strategy	Impact (L, M, H)

5. Market Needs and Competitive Landscape
   5.1. Business justification
      5.1.1. Existing product portfolio
      5.1.2. Primary markets served and major customers
   5.2. Commercialization strategy for target markets
   5.3. Cost of ownership benefits of proposed technology in absolute terms or relative to the cost of the typical current process

6. Company Background and Capability to Meet Technical and Business Targets
   6.1. Team & key personnel
      6.1.1. Management and technical personnel experience and qualifications
      6.1.2. Details on team diversity and explanation of how an institution's Diversity, Equity and Inclusion polices will be operationalized within the project
   6.2. Facilities and equipment
   6.3. Relevant company information
      6.3.1. Three-year financial performance track
      6.3.2. Staff size and make-up by function

6.3.3. IP strategy, key previous innovative developments and intellectual property (patents) held related to the proposal topic

7. Contact Information for Technical Lead, Alternative Technical Representative, and Contract Representative

8. Appendix (if needed – NOT INCLUDED IN PAGE TOTAL)

   8.1. Technical References
   8.2. Letters of Support

If selected to submit a full proposal, the proposal submission will only be accepted electronically up to 5:00 PM Pacific Time on the due date of January 24, 2024. Please submit your completed proposal via email to msig-rfp@semi.org

9. Proposal Evaluation

Upon receipt, proposals will be forwarded to the MSIG RFP review committee comprised of the MSIG PNT technical and governing councils and ARL/DoD subject matter experts (SME's).

If you are awarded funding, MSIG RFP review committee will be invited to the online quarterly reviews. Note, they will not be reading your technical or financial quarterly reports which are only made available to SEMI PNT staff and the DoD.

Proposals will be judged on technical merit, strength of team, benefit to the broader PNT supply chain ecosystem, dual-use technology applicability, impact on SWaP-C reduction, team diversity, and industry awareness activities.

Regarding team diversity, SEMI supports efforts to build diverse and inclusive project teams and workforces because we believe these teams foster greater productivity and innovation in the microelectronics industry. Diverse project teams, including women and other under-represented groups, can bring a more diverse problem-solving set of lived experiences. Therefore, we encourage proposers to create diverse and inclusive teams which recognize, appreciate, and use the talents and skills of employees of all backgrounds.

During the final selection process of proposals, some communication or negotiation between the potential supplier and representatives of ARL and/or SEMI may be initiated over the terms, conditions, specifications, deliverables, schedule or other relevant factors contained in the proposal in advance of awarding of a contract. Granting of any awards to proposals submitted in response to this RFP is contingent upon the continued availability of funding from the U.S. Government.

10. PNT 2023 RFP (RFP23) Schedule

The tentative schedule of activities for the 2023 PNT RFP is as follows:

May 22, 2023	Gap Analysis Workshop held to discuss the technology gaps in the 3 thrust areas of this RFP. Project recommendations have been included in this RFP.
October 26, 2023	RFP Issued to SEMI Member Companies
November 2, 2023	RFP Announced to non-Member Companies
November 14, 2023	SEMI MSIG Positioning, Navigation, and Timing (PNT) PNT23 Proposal Webinar View On-Demand by Registering here: PNT RFP 2023 Proposal Webinar.

November 28, 2023	White Paper(s) Due
December 15, 2023	Notification of White Paper Acceptance and Full Proposal Request
January 26, 2024	Full Proposal(s) Due
March 7, 2024	Notification of Award (each full proposal point of contact will be notified)

The RFP Schedule is subject to change based on availability of review personnel, commitment of federal funds, and other factors.

11. Resources

Information on SEMI can be found at www.semi.org, and MSIG at www.msig.org.

Additional information and guidance on prospective proposal partners may be available and should be requested via email to msig-rfp@semi.org Please include a brief description of your institution's competencies/contributions and highlight the type of institution/partner that would increase the quality, maturity, or commercial viability of your ideas.

A corresponding online webinar explaining the RFP details and answering questions will be held on Tuesday November 14, 2023 start at 8:00am Pacific Standard TimeThe main webinar topic is to review white paper and proposal requirements and answer any questions from the public. If you are reading this after November 14th, this webinar can be watched on-demand by registering at PNT RFP 2023 Proposal Webinar.

12. Contact Information

Communication and questions during the proposal period should be directed to msig-rfp@semi.org .

13. Appendix – PNT Gap Analysis Summary

The PNT 2023 Gap Analysis Workshop was held on May 22, 2023 to discuss technological gaps in the positioning, navigation, and timing R&D regarding this RFP's three thrust areas. Attendees from SEMI, the US Government, academia, and industry attended. The nine currently funded PNT projects gave project introductions and then the attendees separated into three thrust area discussion groups to discuss gaps and pain points in the current PNT technology area. Here are the summary outlined notes of the thrust area discussions.:

Thrust Area 1: Novel Materials, Fabrication, & Packaging Techniques for Low-SWaP Inertial and PNT Sensors:

1) New Materials
    a) Fused Silica, 3D (high Q)
        i) Conductor (metal layer), electrode integration
        ii) Wafer level glass blowing
        iii) Repeatability
        iv) New equipment, process for glass blowing
    b) Piezoelectric (ALD)
        i) PZT, AlScN
        ii) Limited in thickness
        iii) Integrate with other materials
    c) Non-metallic electrode
    d) Physical Trimming
    e) Anti-stiction coating for high temperature
        i) Low g accelerometer
        ii) Anti-charging
2) Packaging challenges
    a) Miniaturized stress isolation solution
    b) 3D packaging
    c) Packaging materials (low stress die attach, stable)
    d) Measurement stress, compensation/correction
    e) Vibration
3) Test
    a) Performance metrics
    b) Platform dependent (size, application)
    c) No standard test protocol/facility
    d) post-fab trimming
    e) self-test
    f) test cost reduction, test method
    g) accelerated life test
    h) M/L

Thrust Area 2: Advanced Active and Passive Integrated Photonics for Low-SWaP Atomic Clocks, Quantum Systems, and PNT Sensors

1) What's lacking?
    a) Passive Photonics
        i) Interfacing I/O to PICs
            (1) Relevant to VIS/IR quantum systems
            (2) Grating couplers, Edge Couplers, Evanescent Couplers
            (3) Desire generalized optical 'photonic wirebonding' capabilities.
                (a) 3D printed optical polymer space wirebond
                (b) Chip-to-chip; laser to PIC; fiber to PIC

(c) Low Backreflection Coupling
(d) Feedback insensitive
(e) Materials that cover UV/VIS/near-IR
ii) Optical Isolators
(1) Smaller, improved rejection
(2) Minimal magnetic fields
iii) Large area out-couplers (mm or better)
(1) Metasurface out-couplers
(a) Inverse Engineering approaches
(2) Alternatives to gratings
iv) PIC Integrated micro-optics
(1) For solid angle issues
(2) For coupling challenges
v) General approaches to Stray Light Mitigation
(1) Beam dumps
(2) Light Traps
(3) Scattering minimization techniques
b) Active Photonics
i) Feedback Insensitive Lasers
ii) High-speed tuning of PIC-based Lasers
(1) PZT-based actuation
iii) Multiple wavelength Lasers on single PIC
(1) Common mode noise rejection
iv) Integrated or Integratable Optical Amps
(1) Er-doped glasses (Er:Al_2O_3); Semiconductor Amps; Tapered Amps
(2) w/ Feedback minimization at higher powers
(3) w/ Heat management at higher powers
(a) Integrated Heat Sinks
v) Manufacturable Chip Scale Frequency Combs
(1) Separate Module vs Integrated.
(a) Is it Manufacturable as a separate module?
(i) Micro Combs
1. Heterogenous Integration is a challenge
2. Desire relevant self-referencing comb module at the board or chip-level
vi) Detectors
(1) High collection efficiency in UV/VIS
(2) Low backreflection
(3) Micro-PMTs in UV/VIS
(4) Low stand-off distance detectors
(5) Photon Counters
vii) High Finesse Optical Cavities (integrated)
(1) Reliable commercial sources
viii) High efficiency frequency converter
(1) Micro Acousto-optic Modulators
(2) High extinction on demand
ix) Modulators
(1) Reliable Lithium Niobate fabrication
(2) Low Frequency (non-$LiNbO_3$) modulators (sub 200MHz)
(3) Ultra Low Power modulators (nW)
(4) Optical Switches
2) Early Stage Challenges
a) Monolithic Integration
i) Similar to Indium Phosphide capabilities but for other wavelengths (i.e. GaN or other material systems)

   b) Delivered Power in the 10s of mW (10-100mW) for Cold Atom PNT (Inertial)
3) Fundamental Late-Stage Non-Differentiating Areas
   a) Fabrication to Testing
      i) Requires packaging at low-volumes/costs with flexible designs
   b) Manufacturability testing
      i) Inverse design for manufacturing post proof-of-concept
   c) General integration or packaging techniques
      i) Space qualified versions
   d) Environmental qualification and Life Testing of PIC-based Laser systems
      i) Large sample size
      ii) Production based techniques
      iii) Target telecom-style testing and validation

Thrust Area 3: Advancements Towards Low-SWaP, GPS-Free PNT Technologies

1) Request: We always talk about needing navigation when GPS is denied, **but for how long will GPS be unavailable?** The answer greatly changes the tech options.
2) Opportunities:
   a) New Materials for microdevices need to be investigated (in addition to SiC)
   b) New fab tech, such as:
      i) Better etching – improved sidewall surfaces, profiles and aspect ratio in conventional materials such as silicon
      ii) Etching capability of new materials
      iii) New deposition methods for better uniformity and/or new materials
   c) Packaging technology for MEMS and systems to support reduced SWAP-C
   d) Optical technologies are disruptive and should be funded at component and system levels
   e) Timing: high performance resonators and oscillators that perform as well as OCXs are needed
   f) Software:
      i) Machine Learning continues to show promise (could reduce SWAP-C by allowing a smaller, lower performance inertial sensor to match the performance of a larger, high-end device
      ii) Equivariant filters are interesting – can they be used effectively in sensor fusion?
   g) Sampling methodology studies
      i) Sparse sampling methods for lower compute overhead and lower power
   h) Vision systems for navigation
      i) Methods for establishing ground truth with landmarks
      ii) How to get and use pre-mapped data
      iii) Lower power vision systems by only registering changing pixel (was it Prophesee that did this?)
      iv) Combo/Fusion systems:
         (1) Radar and camera
         (2) IMU + vision system
         (3) Could alternatively focus not on *what* sensors to use, but rather *how* to fuse and use the data quicker and faster with lower power
            (a) Techniques to fuse multiple sensors to allow lower power and performance
   i) GPS alternates
      i) Other satellite systems
      ii) Ultra wideband (UWB), RF, beacon references
   j) Multifunctional use material, for example:
      i) CMOS MEMS (mems devices made from a standard CMOS wafer or process)
      ii) Ferroelectrics
      iii) ALD materials
      iv) PZT, AlScN

- k) Should find a to fund foundry MPW runs
- l) Testing can be half of the part or system cost
    - i) Fund testing development, especially with an eye towards scalability
    - ii) Cheaper testing hardware (ex, Asygn is making a smaller, cheaper version of a Zurich locking amplifier, and Inertial wave is putting whole locking amplifies systems on a chip)
    - iii) A benchmarking study to document MEMS test methods and the trajectory for the testing tech would be valuable
- m) Prototype assembly and testing houses would be helpful
    - i) Perhaps start with a survey of test and packaging houses to see who would be interested in setting up this kind of model (which cost share)

3) There were comments about exploring opportunities to leverage the CHIPS Act and new fabs for MEMS. Good idea but out of the scope of this gap analysis