Sea-Skimming Missile Tracking Radar Array (SEMTA) System

Air Force Topic AF191-051

DoD SBIR Kick-off Meeting

September 30, 2019

Period of Performance: 9/3/19 – 6/2/20

Presented To:

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Presented By:

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Sea-Skimming Missile Tracking Radar Array (SEMTA) System

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Review of Air Force Needs

- The United States Air Force is seeking a means to improve target tracking over water ranges utilizing unmanned surface vehicles (USVs). The intended target is a sea-skimming missile flying at a supersonic speed at altitudes of up to 100 m.
- Testing on water ranges is currently limited by the inability of land-based and barge-based radars to track over-the-horizon. Full use of the Gulf of Mexico is required for test missions requiring system under test tracking. A new surface-to-air radar system for use on an USV would significantly increase target tracking coverage over water.
- Using a fleet of autonomous USVs would enable the Air Force to leave the radar systems in the sea for long periods of time between the tests and wake and configure them for testing on demand. However, currently, no existing system that can address this need.
- The system would need to be optimized for an unmanned surface vehicle that is approximately 10 feet long and 2 feet wide. The system must weigh less than 100 pounds and fit within a 6 inch by 12 inch by 12 inch payload box.

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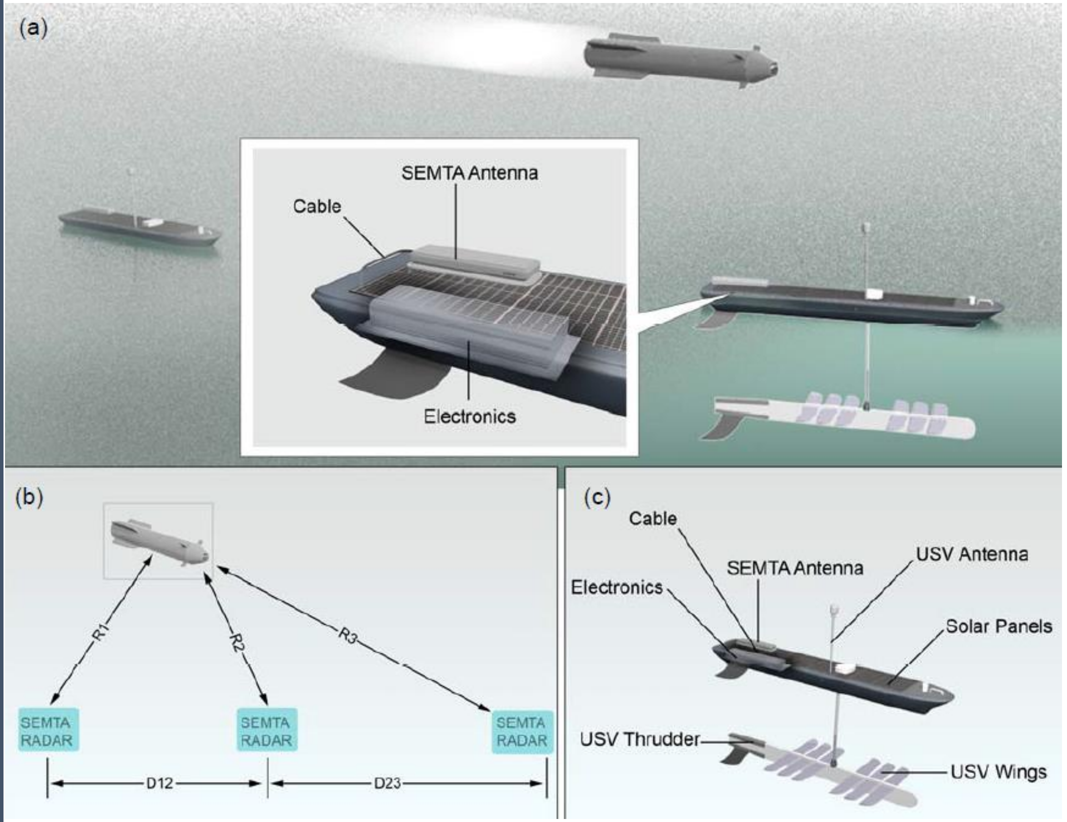
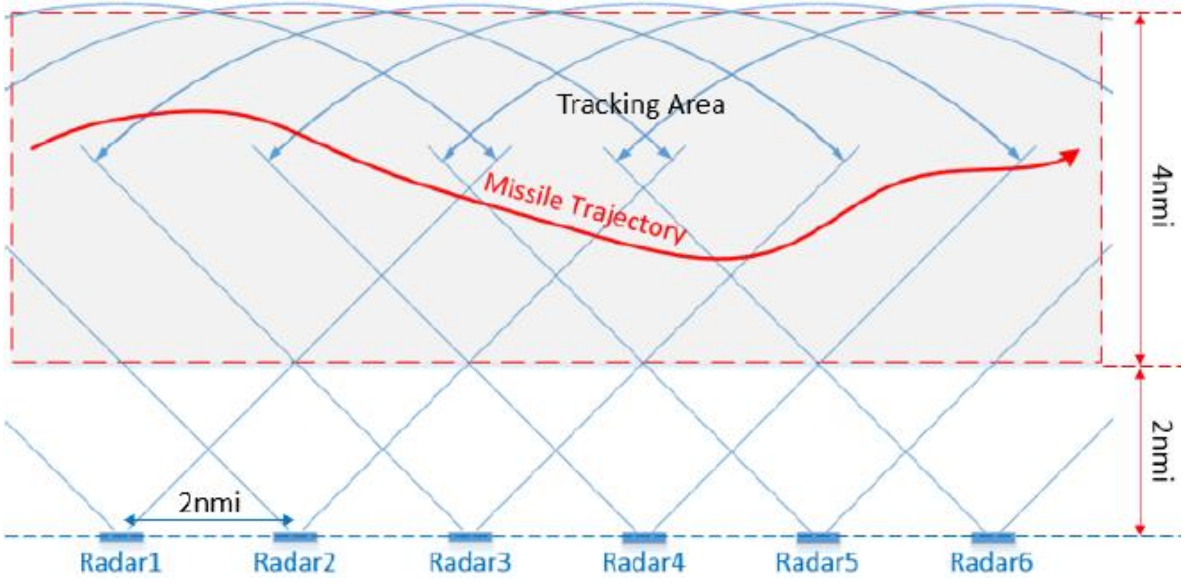
ISI's Solution: The SEMTA





- SEMTA system enables tracking of a sea-skimming missile during the test flight. SEMTA radars are positioned in a scalable linear array configuration along the target trajectory to create a composite over-the-horizon FOV. Multilateration is applied using data from at least two radars to calculate the target position with <10 m accuracy at ranges up to 6 nmi.
- The SEMTA tracking software collects and fuses data from all of the radars in the array and computes the composite target flight trajectory. The compact radars, installed on a USV, utilize the USV's power, GPS, and communication systems and control its movements to compensate for the hydrodynamic forces.

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ISI’s Solution: The SEMTA (cont.)

- The radar system operates in X-band and includes a 1D linear antenna array that enables electronic beamsteering capability in horizontal direction. The planar antenna has 11 in. × 11 in. aperture. The antenna provides a pencil beam with 7° beamwidth in both horizontal and vertical planes. SEMTA is expected to consume <50 W and can be powered by the USV’s solar panels.
- SEMTA, designed specifically to track targets from USVs, is tolerant to the inherent instability of USVs caused by hydrodynamic forces. The USV’s pitch, roll, and yaw movements will have little effect on the multilateration accuracy until they exceed ±3° in vertical and ±10° in horizontal (yaw) deviations from the nominal position, which might shift the radar’s FOV. To operate in high wave sea condition SEMTA will utilize mechanical stabilization of the antenna panel. We expect a simple gimbal mechanism will be capable to keep the antenna vertical plane (+/-2°) will satisfy SEMTA requirements.
- USV pitch/roll/yaw sensors will be used to verify the radar operates in proper conditions and to correct the calculated position coordinates.
- SEMTA applies pulse-Doppler with phase coded pulse compression radar technology, which provides high radar sensitivity and resolution between different radar signals.
- SEMTA uses frequency diversity and m-of-n binary integration algorithm to reduce effect of the target RCS fluctuation and provide high probability of detection of the low RCS targets with very low false alarm rate.

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Advantages over Current Approach

The proposed system has the following advantages over the current approach in terms of benefits to users:

- SEMTA's array operation **reduces its size, weight, power, and cost (SWaP-C),** and **simplifies the design** without affecting the tracking accuracy.
- **Compact low-cost radar**, specifically designed for installation on USV, fits into the payload box and leaves more than 50% of the space for an additional battery or other equipment.
- Tracking **low-altitude low-RCS** targets moving at **supersonic speed up to Mach 2.4** at 6 nmi range.
- **Scalable multi-sensor architecture**, enabled by independent operation of the system radars, allows for **over-the-horizon tracking**.
- Server-based **tracking algorithm** creates an **accurate composite radar image** by using advanced computation-efficient algorithms for data association and state estimation.
- **High tolerance to USV movements** greatly simplifies the system hardware and software, increases robustness, and decreases the system cost.

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Phase I Work Plan

Phase I Goals and Objectives

The overall goal of this project is to address the Air Force need by developing and, for the first time, demonstrating the feasibility of SEMTA. The following specific objectives have been established to reach this goal.

Phase I Objectives:

- Objective 1. Definition of the system requirements considering the Air Force’s requirements.
- Objective 2. Definition and development of the system architecture.
- Objective 3. Feasibility demonstration of the SEMTA system.
- Objective 4. Definition of the commercial market for SEMTA technology.

Project Focus:

1. Detection of low RCS and high-speed targets
2. Low altitude 2D target position determination
3. Radar unit schematic design and its verification with the test
4. USV movement and antenna stabilization

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Project Tasks

Task 1. Define the System Requirements and Develop System Architecture (Objective 1)

After determining the system requirements in consultation with the Air Force team ISI will develop system architecture, including radar hardware, modulation waveform, antenna type, signal processing algorithm, and stabilization methods. ISI will develop SEMTA simulation model in MATLAB.

Task 2. *Develop the Transceiver Design (Objective 2)*

ISI will develop the SEMTA transceiver design, including selection of main components, and analyze its performance and SWaP-C.

Task 3. ***Develop the Breadboard Prototype (Objective 2)***

ISI will develop a breadboard prototype based on components selected in Task 2. ISI will build and test the prototype.

Task 4. *Develop the Stabilization Solution (Objective 2)*

ISI will investigate the USV's built-in stabilization capabilities and develop the algorithm that mitigates hydrodynamic forces. ISI will work closely with the subcontractor Liquid Robotics to understand the USV's capabilities and develop the solution that provides required performance.

Project Tasks (cont.)

Task 5. ***Determine Feasibility of SEMTA System (Objective 3)***

ISI will develop a test plan for SEMTA design evaluation. ISI will test the breadboard prototype and extrapolate the measured performance to the SEMTA radar unit and SEMTA multistatic system. ISI will analyze the measured and simulated results to demonstrate the feasibility of SEMTA.

Task 6. ***Explore Commercial Potential, Technology Transition, and Product Viability (Objective 4)***

ISI will explore the potential to transfer SEMTA to military systems and civilian applications. Market research will identify the most promising applications of the SEMTA system. Sources of Phase II and Phase III guidance and matching funds will be identified early in the project, and these early business partners will be involved throughout development and commercialization.

Task 7. ***Manage Program and Submit Reports***

ISI will undertake program management and reporting, as well as communication with the Technical Point of Contact (TPOC). ISI will prepare and submit reports and attend a kick-off meeting in accordance with contractual requirements. The final report will contain a summary of the work performed as well as recommendations for work to be performed in Phase II.

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Performance Schedule

TASK SCHEDULE	MONTHS AFTER PROJECT INITIATION								
	1	2	3	4	5	6	7	8	9
1. Define System Requirements & Develop System Architecture	→	→	→						
2. Develop the Transciever Design		→	→	→					
3. Develop the Breadboard Prototype			→	→	→				
4. Develop the Stabilization Solution			→	→	→				
5. Determine Feasibilty of SEMTA System				→	→	→			
6. Explore Commercial Potential	→	→	→	→	→	→	→	→	→
7. Manage Program and Submit Reports	→	→	→	→	→	→	→	→	→
Milestones	1					2			3

1. Kick-off Meeting
2. Technical Review
3. Final Report

Period of Performance: 9/3/19 – 6/2/20

Funding: S149,999

Technical Discussion

Define the System Requirements and Develop System Architecture (Task 1)

- ISI will determine hardware requirements for micro-radar system as well as tracking algorithm, antenna type, and stabilization methods in consultation with the Air Force team.
- Based on the system requirements, ISI will develop the SEMTA system architecture including a radar unit and multi-unit operation.
- ISI will model the SEMTA system and its components in MATLAB, including the target model, sea clutter model, USV platform model, radar model, multistatic radar configuration model, and tracking model. All the models will be adapted to the SEMTA requirements.

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Define the System Requirements and Develop System Architecture (Task 1) (cont.)

Possible low altitude weapon under test has a widely varying distribution of the RCS versus aspect angle. The RCS can vary from +20 dBm^2 for fuselage specular return to -40 dBm^2 for some non-specular aspect angles. SEMTA radar units will use frequency diversity which allows to decorrelate target return, and, combined with m-of-n binary integration, provides high probability of detection of low RCS targets with very low false alarm rate. We expect to detect a target with RCS as low as -20 dBm^2

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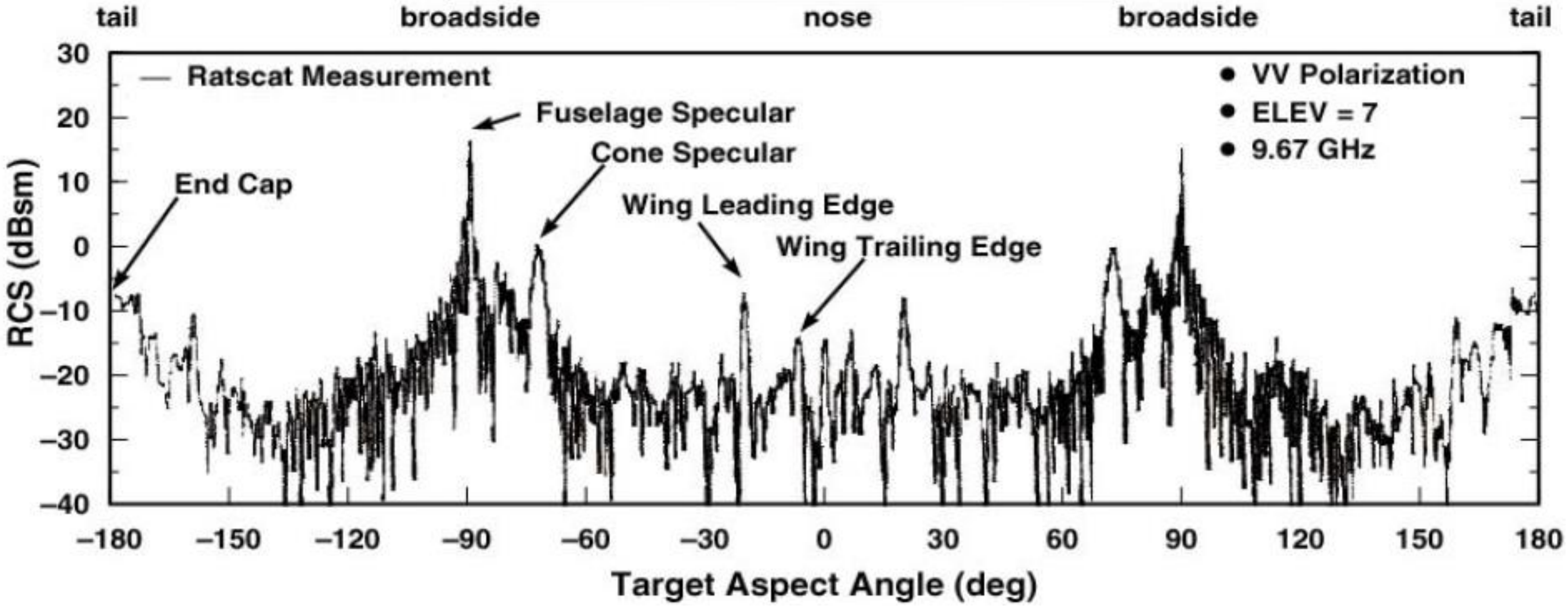

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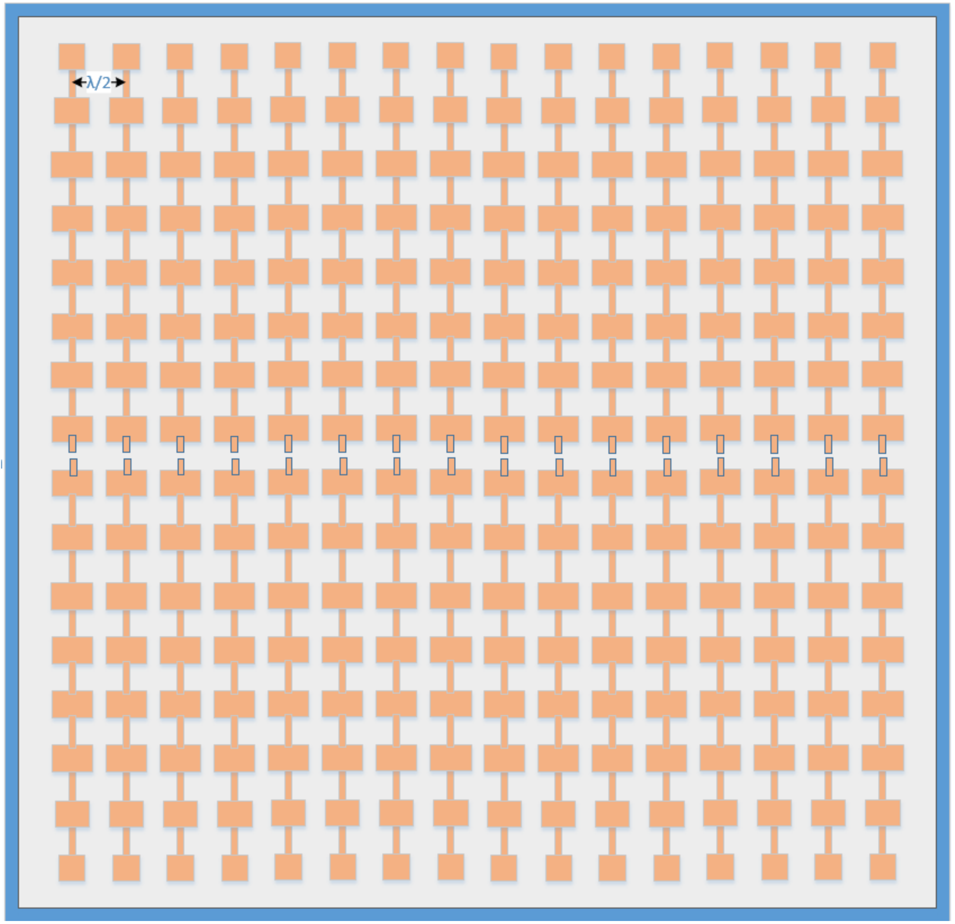
Define the System Requirements and Develop System Architecture (Task 1) (cont.)



- To detect low RCS target, high antenna gain (about 27 dB) will be used to maximizes radar sensitivity in the limited SWaP.
- The planar antenna (11in. × 11 in.) contains a 16-element 1D linear array placed on the side of PCB made with low losses Rogers material.
- Each antenna element (line) is fed from the via at the center of the line.
- Transceiver's RF components may be located on the back side of the same PCB to reduce interconnection losses and radar C-SWaP.
- The antenna has a 7° pencil-type beam, electronically scanned in horizontal direction.
- Antenna operational bandwidth is ≥300 MHz (500 MHz objective) in order to support frequency diversity operation.

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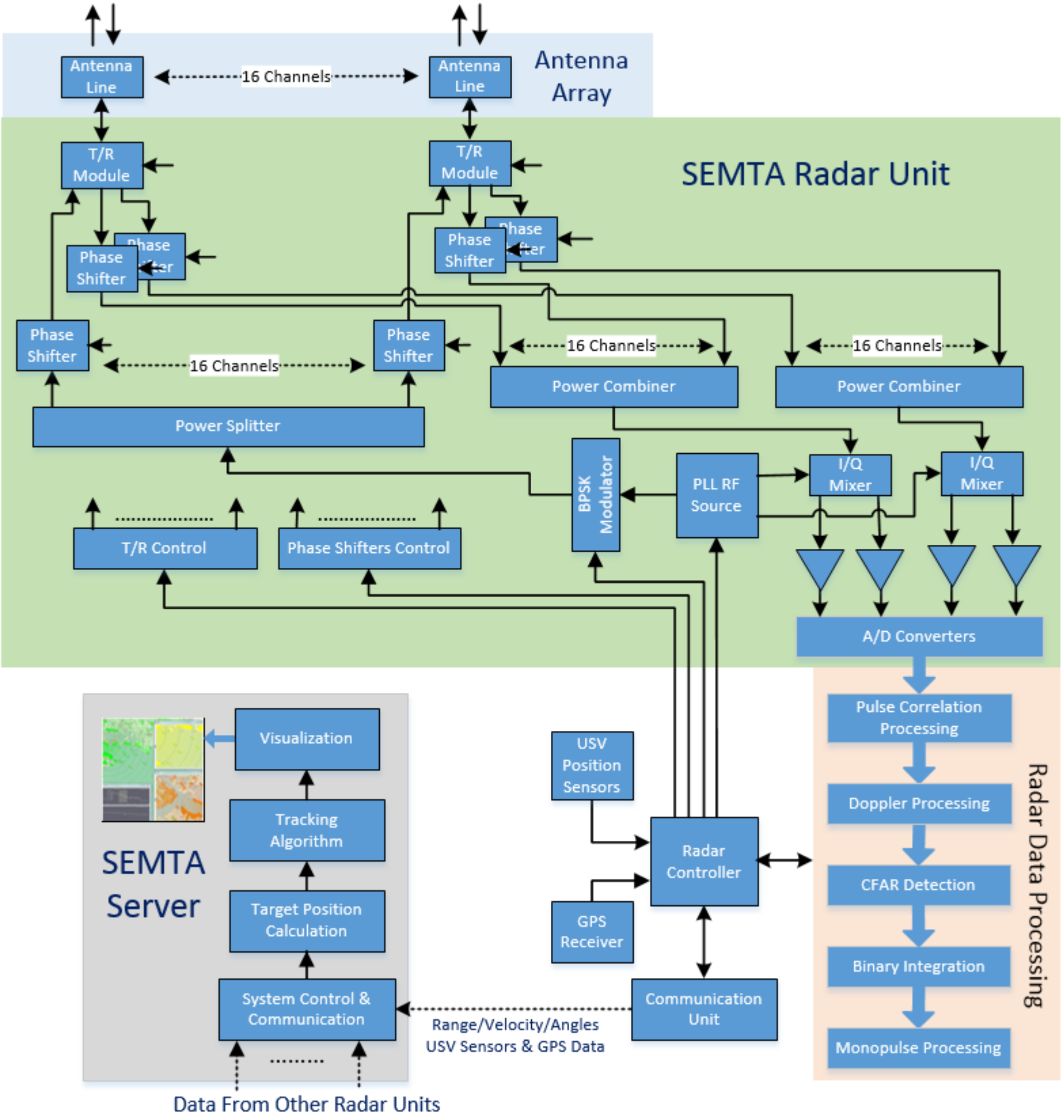
Develop the Transceiver Design (Task 2)

- SEMTA radar system operates in X-band and uses pulse compression operation with high (about 20%) duty cycle to improve radar sensitivity.
- Bi-phase intra-pulse coding with different codes for different radar units allows to simplify the units separation.
- Receive array has dual phase shifter chain for horizontal monopulse operation in radar tracking mode.
- Using PLL synthesizer as radar carrier source enables frequency agility mode to reduce target RCS fluctuation and improve probability of detection.
- We plan to use commercially available integrated transmit and receive (T/R) modules with 4 W transmit output.



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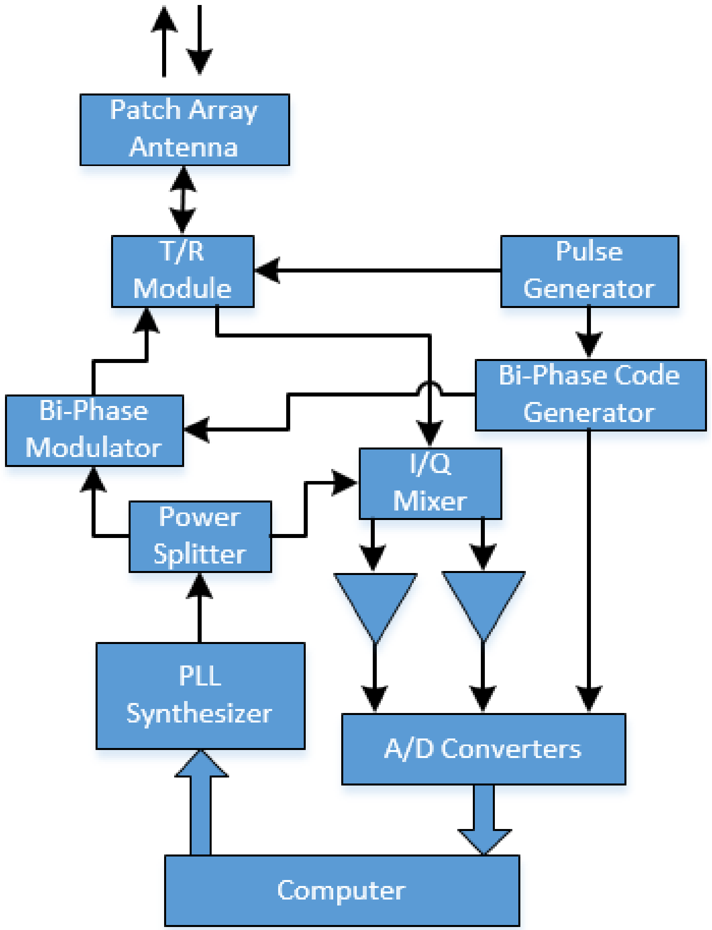
Develop the Breadboard Prototype (Task 3)



- ISI will determine feasibility of the SEMTA technology based on both, simulation results and radar breadboard prototype test.
- ISI plan to build radar breadboard prototype by using COTS components: fixed beam patch array antenna (e.g. SAM-1031131607-90-L1), integrated T/R module (e.g. QPM2637), and PLL synthesizer (e.g. ADF5610). To avoid time and money consumed PCB design, most of the prototype parts will be procured in evaluation board format.
- The radar prototype will use the same pulse compression configuration with bi-phase code as SEMTA radar. Using a fixed beam with single T/R module instead a 16-channel phase array in SEMTA will results in no multi-beam capability and reduced max range of the breadboard prototype. However, we can easily recalculate the breadboard performance to complete SEMTA radar unit to verify our design projections.
- We plan to provide the radar breadboard test in sea environment. The breadboard prototype will be located on the Pacific Ocean beach in the Torrance, CA area. Boats in the beach area will be used as targets during the test.

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Develop the Stabilization Solution (Task 4)

- ISI will investigate the USV pitch/roll/yaw inherent stability and its control capability before defining a radar stabilization solution. We will attend Payload Developer's training at Liquid Robotics facility to learn about the stabilization control capabilities available for Wave Glider 300.
- Since, the SEMTA approach is based on the accurate range measurement and use of the multilateration algorithm for target positioning rather than angular type positioning, we can avoid incorporating a complex and expensive mechanical stabilization to achieve a very accurate antenna pointing angle. The mechanical stability of the radar antenna is limited only by the antenna beamwidth and does not require a target angular accuracy for the target detection. Thus, SEMTA radar antenna has a rather narrow (for a compact system) 7^o beam, but this value is still two orders of magnitude higher than the angular accuracy required for 10 m target position accuracy at 6 nmi range. Also, the electronic beam steering of SEMTA radar, combined with horizontal monopulse capability, allows to compensate for USV platform yaw excursion by electronically changing of the antenna beam.
- Vertical beam pointing is the most sensitive parameter for SEMTA radar system, because it uses just a fixed 7^o beam in vertical direction. We plan to use a simple gimbal mechanism to keep the antenna beam deflection within $\pm 2^o$ from nominal position. We will analyze the gimbal control solution and define it in this task.

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Determine Feasibility of SEMTA System (Task 5)

- ISI will determine feasibility of the SEMTA approach by simulating the MATLAB model of the SEMTA multistatic radar configuration and evaluating system performance for various target trajectories, RCS, and velocities.
- ISI will also use breadboard prototype test results to extrapolate the SEMTA radar performance parameters, such as accuracy, minimum and maximum ranges, minimum and maximum target velocity.
- ISI will analyze the breadboard prototype test results, compare them with simulation results, and adjust the simulation model in the case of discrepancies. The verified (after adjustments if required) radar design, radar configuration, and tracking algorithm will advance the SEMTA system and determine its feasibility.
- The results of this task will be presented to the Air Force team as demonstration of feasibility of SEMTA technology and reported in detail in the Final Report.

Project Team

Mr. Victor Khodos, Sr. RF Engineer
Principal Investigator

Mr. Alexander Genusov, Director, Electronic Systems Development
Architect and Project Manager

Sen Holloway, Electronic Engineer
Modeling and Breadboard Prototype

Dr. Min-Yi Shih, VP and General Manager
Program management

Mark Thompson, Director, Business Development
Commercialization and technology transition

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Commercialization Strategy and Transition

Product Vision. SEMTA radar will be installed on USVs and used for tracking an airborne target during tests. The compact radar device will fit into the USV instrumentation box (size), weigh <10 lb, and consume <50 W of power during operation. The SEMTA multi-radar system will be capable of providing continuous tracking of a single target by using a large scale formation of USV-based radars along the known trajectory of the target under test. SEMTA tracking software will provide highly accurate 3D position of the target (<10 m accuracy) during its flight.

Target Military/Government Applications. SEMTA's primary application is in DT&E for long-range airborne targets over a large area of water. Other DT&E applications will benefit from the scalability of the SEMTA radar system. SEMTA will be adapted for security and surveillance applications that can benefit from a multi-sensor detection and tracking system, such as those used by the DoD, especially the Navy and U.S. Coast Guard.

Target Commercial Applications. SEMTA can be used for commercial DT& with minimal/no modifications. SEMTA can also be used in security of oil rigs and offshore platforms and in ground-based installations to replace large, expensive radar systems with a scalable array of miniature low-cost radars.

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Program Management and Deliverables

- Kickoff meeting
- Interim progress reports
- Periodic discussions of the development and simulation/test results
- Conference minutes
- Presentation material
- Draft final report
- Final report
- Invention report
- Close-up meeting

- **Q&A**