Portable Anti-UAS Device (PAN-UAS)

Army SBIR Phase II Kick-off Meeting

February 15, 2019

Period of Performance: 2/1/19 – 5/31/21

Presented To:

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Agenda

1. **ISI Background**
2. PAN-UAS Program Objectives
3. Phase II Development Plan
4. PAN-UAS system architecture
5. Antenna and RF Module
6. Digital Module
7. DSP algorithm
8. Tracking algorithm and Control SW
9. Jammer
10. Mechanical enclosure
11. Test and demonstration of the PAN-UAS prototype
12. Commercialization and Program management
13. Open Discussion

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Company Background

Privately held as a wholly owned subsidiary of Physical Optics Corporation, since February 2018

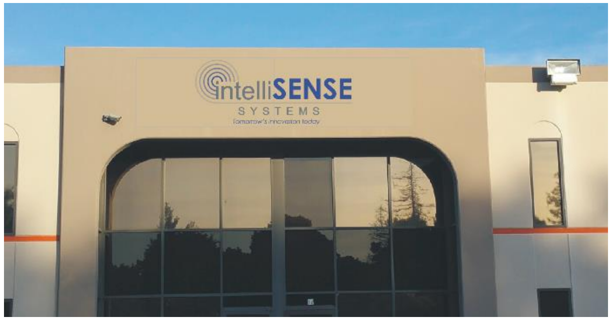
Current business is built on 3 decades of technology transition experience

2018 revenues ~ $30million USD

40% SBIR - 30% Tech transition - 30% Production

~126 employees (16 PhDs)

Strategic Advisory Board



ISS's Quality Management System (QMS) operates IAW ISO9001:2008/AS9100D, ISO9001:2008/AS9110C, and CMMI-DEV:ML3 standards. As a development organization, ISS incorporates CMMI best practices into its system engineering processes throughout the life cycle of its products.

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What We Do

Intellisense Systems designs, develops and manufactures a wide range of standard and customized integrated electronic systems. These products become part of an OEM, prime contractor's system, or government direct procured equipment. Intellisense Systems products are used across many markets that includes military & defense, homeland security, law enforcement, and commercial.

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Market Strategy

- Pursue growth in markets that lend themselves to IntelliSense Systems capabilities and expertise
  - Build with durable discriminators
  - Program/Platform specific opportunities
  - Intelligent, rugged, light weight, low power
  - High performance and functional density
- Position IntelliSense Systems as a Value-Add Partner
- Build Customer Loyalty through our demonstrated performance
- Maintain and enhance our Technology Leadership
  - Leverage SBIRs to fuel technology and product innovations
  - Demonstrate our leadership by anticipating and satisfying our customers' needs and differentiating our products as preferred solutions
- Broaden our customer and application base where it adds additional value and capabilities to IntelliSense Systems and our customers

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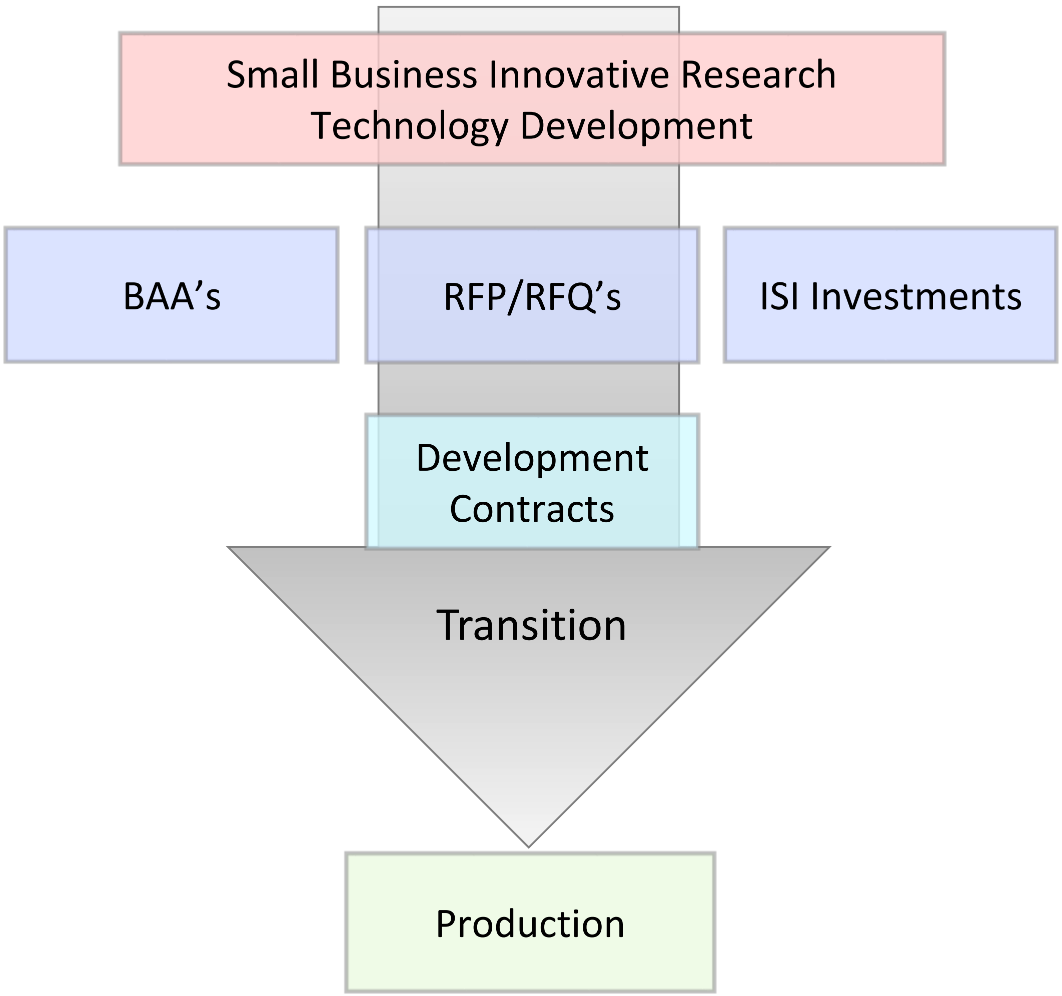
Intellisense Systems Business Model

Focus on Successful Transition of Technology to Commercial Products

- ISO9001, AS9100D and AS9110C Certified
- Weather Sensors Manufactured under a Program of Record
- Production Line for Aircraft and Ground Vehicle Displays
- Transitioning Wearable Equipment Technology
- Certified Independent Financial Audits
- Managed under EVMS & CMMI-MLIII (In process)



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Delivering Critical Technologies to our Customers…

Micro Weather Sensor

Visualization/Displays

Night Vision, Laser Range Finders, Sights

Soldier Power & Data Management

Ballistic Fire Control MET Sensing

Maritime Deployable Weather Sensor

EO/IR & LIDAR Sensing

Augment Intelligence Algorithms

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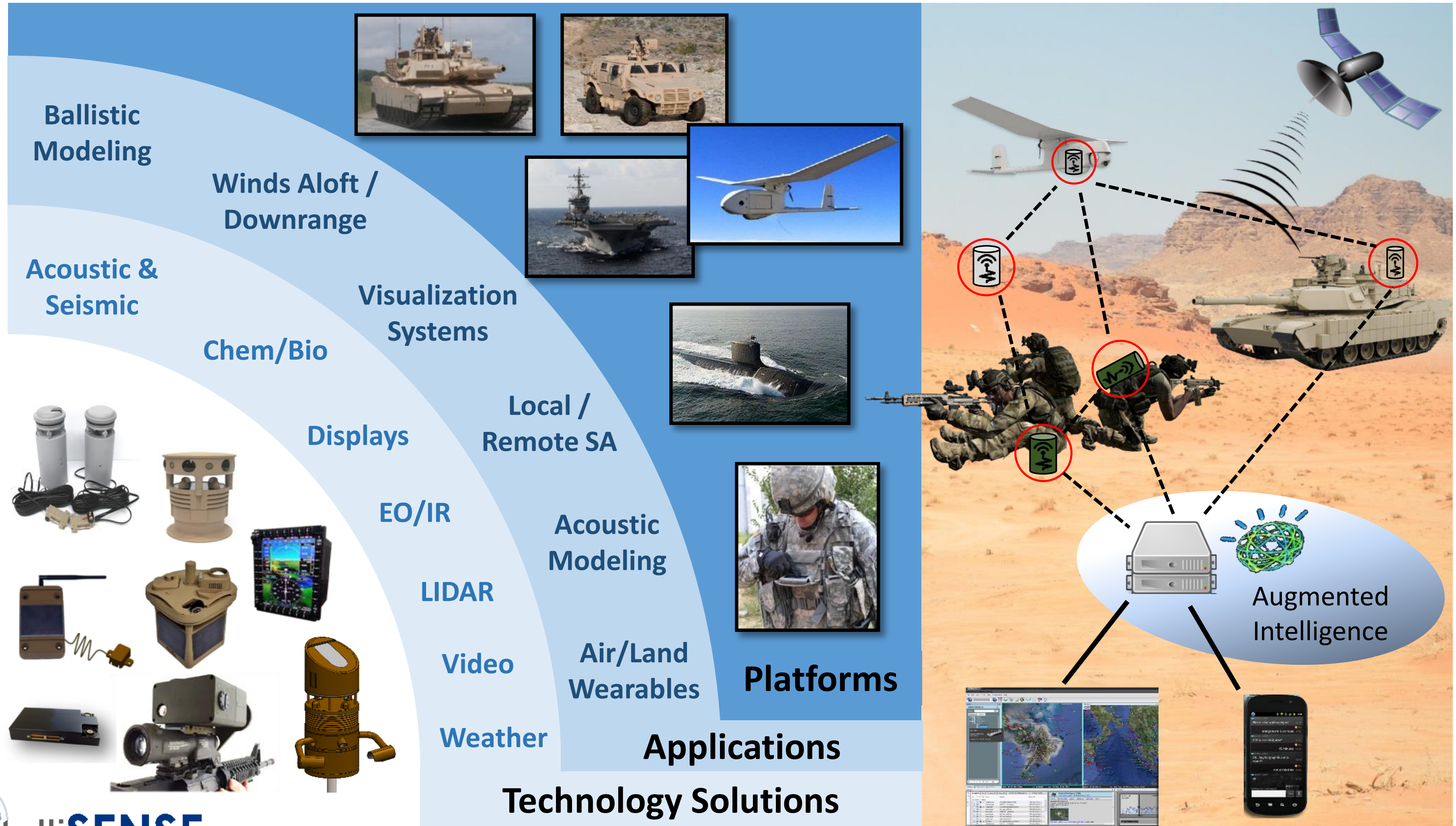
…Where, When at an Affordable Price

Technology Vision



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C-UAS Technologies at ISI

ISI has been developing solutions and technologies to detect and disable / defeat small UAS (Class 1 and Class 2). Our focus has been on the following technologies:

- All-digital MIMO fast FMCW radars operating in the range of 3-6 km that enable compact low-cost implementations of stationary, man-portable, and vehicle mounted C-UAS systems with wide/hemispheric FOV.
- Integration of passive RF, EO/IR, and/or acoustic sensors.
- Integration of C-UAS detection systems with RF communications and GPS denial systems and with kinetic weapon systems.

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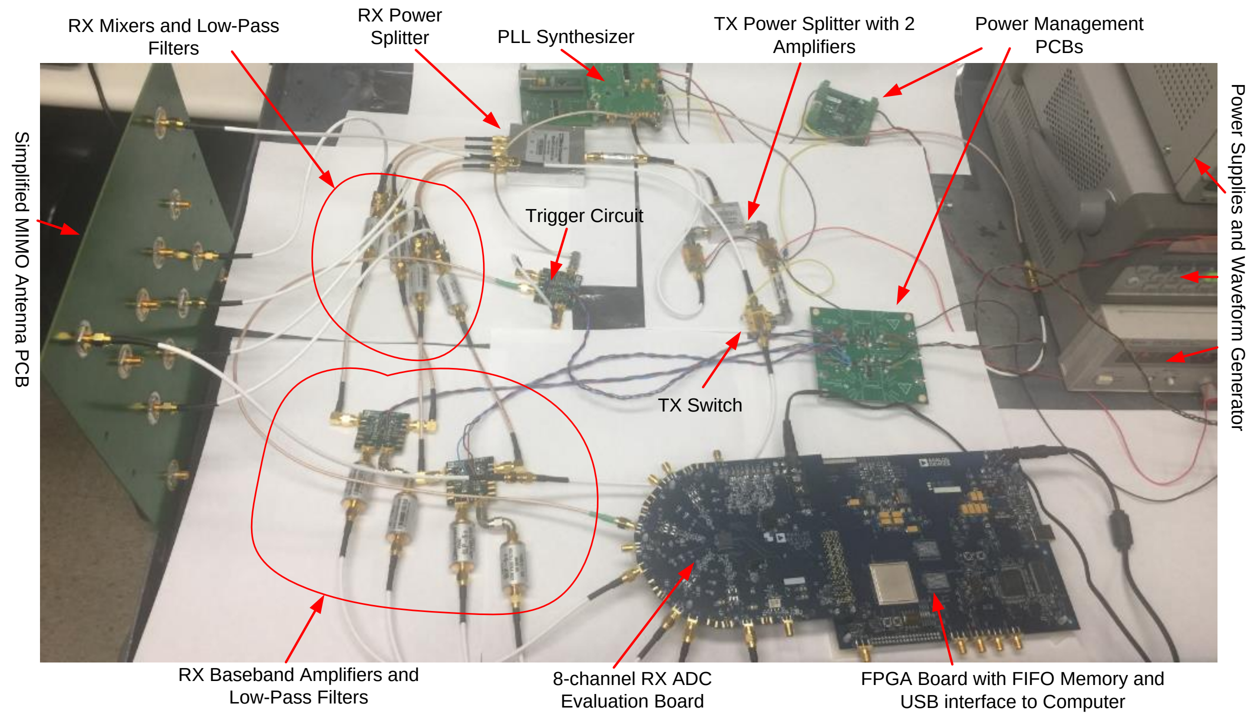
Recent Progress in Radar Development

- ISI has continued its radar development efforts after PAN-UAS-I through a SOCOM effort and other related projects, resulting in a very advanced breadboard prototype.



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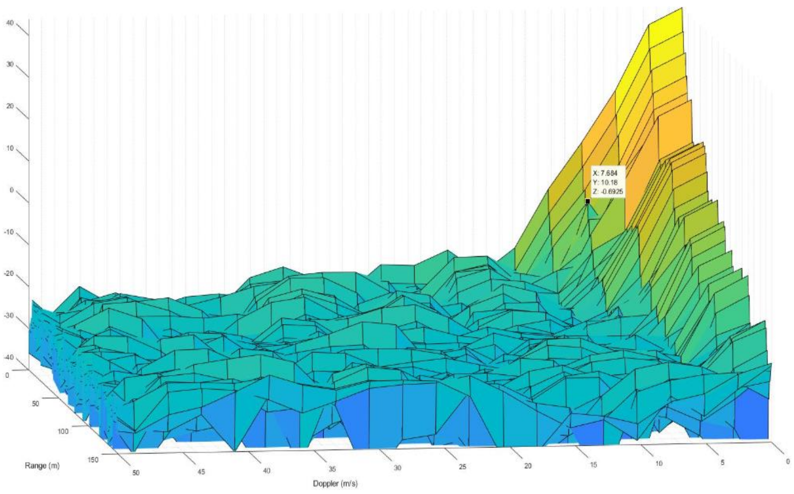
Recent Progress in Radar Development (cont.)

- Initial testing with a very small quadcopter has proven successful in detecting both static and moving targets.
- Building on this technology in PAN-UAS-II will leverage this earlier development to further accelerate development.



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Review of Army Needs

- The Army is seeking man-portable, squad-sized technology to detect and counter unmanned aircraft systems (UASs).
- Current Army tactics are not effective against individual and swarms of UASs, especially when away from a dedicated power source such as a base or vehicle.
- Current technologies capable to effectively counter UAS threats leave a gap for a portable system to detect and counter UAS threats against a squad or platoon.
- Although small UASs have been predominantly utilized for surveillance and reconnaissance missions, the recent trend is towards the weaponization of low-cost highly available UAS systems, making them more lethal players on the battlefield and rendering the need to fill this technology gap much more urgent.

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PAN-UAS Program Objectives

Program Objective: *To provide each squad with the technology required to detect and disrupt/destroy UAS threats, attacks, and maneuvers.*

Phase II Objectives:

- ❑ Develop a breadboard prototype of the PAN-UAS system implementing a safe and effective capability that is optimized for use in a tactical military environment.
- ❑ Demonstrate PAN-UAS real-time operation against UAS systems along with the identified “host” system at a Technology Readiness Level (TRL) of 5/6.
- ❑ updated cost, schedule, and performance baseline as a subcomponent to the host system of phase III.
- ❑ Meet SWaP-C requirements: volume <100 in3, weight < 3 lb., cost <$15k, and battery powered operation.

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Phase I Results

ISI completed four trade studies and reached the following technical conclusions regarding the UAS threat problem:

- Current COTS solutions cannot meet Army SWaP-C requirements.
- Jamming of GPS or RF control frequencies can be used to prevent UASs from following the flight plan (either manual or automatic) established by hostile forces.
- Radar is the best technology for detecting and tracking UASs in a large area of sky to meet the Army's SWaP-C requirements and can be co-mounted with existing tripod-mounted scopes or operated in a fully stand-alone mode.
- It was determined that a small, scanning radar combined with a RF jammer is the optimal solution to meet all Army requirements.

Based on these conclusions, ISI developed PAN-UAS system concept, verified its performance in simulation, and defined the development plan for system prototype.

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Project Scope and Development Approach

- ISI will develop the PAN-UAS system prototype, including electronic circuits, embedded software, and mechanical enclosure.
- ISI will integrate the prototype, evaluate its performance, and demonstrate its operation.
- ISI will explore commercialization of PAN-UAS technology and prepare a technology transition plan that will be implemented in Phase IIe and/or Phase III.
- ISI will use concurrent development of system components and incremental integration and testing to achieve the full functionality with minimal design iterations.

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Phase II Task Outline

- Task 1. *Define System Architecture and Modes*
  - Review and refine PAN-UAS system architecture based on Phase I results, requirements, and recent ISI experiences.
- Task 2. *Develop Antenna Structure*
  - Develop a new MIMO (multi-input, multi-output) antenna structure that can produce an accurate, high-resolution digitally scanned beam.
- Task 3. *Develop RF Module*
  - Develop an RF module as a single circuit board that drives the antenna structure to implement scanning detection as well as jamming when UAS threats are detected.
- Task 4. *Develop Digital Module*
  - Develop a digital sampling system for controlling the transmitters and processing outputs from each antenna element in the combined antenna structure and RF system.
- Task 5. *Develop Signal Processing Firmware (Objective 2)*
  - Develop firmware to control all functions of the digital control system and sampling system, including the fast multi-chirp radar waveform, jamming signal waveforms, and multi-mode power management.

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Phase II Task Outline (cont.)

- Task 6. *Develop Mechanical Packaging*
  - Develop mechanical packaging for the final PAN-UAS radar system to allow for unimpeded operation and to meet military standards for environmental ruggedness and electromagnetic compatibility.
- Task 7. *Iterate Design Based on Initial Testing*
  - Based on initial results from each element of the PAN-UAS design, ISI will perform a design iteration to optimize performance prior to final fabrication.
- Task 8. *Fabricate Final System*
  - Fabricate the final system for testing and evaluation.
- Task 9. *Perform Performance Testing and Demonstration*
  - Perform initial functional and performance testing at ISI facilities followed by testing with a selected host system at a location selected by the Army.
- Task 10. *Commercialization and Transition Strategy*
  - Define the plan to transition PAN-UAS into military and commercial applications.
- Task 11. *Manage Program, Mitigate Risks, and Submit Reports*

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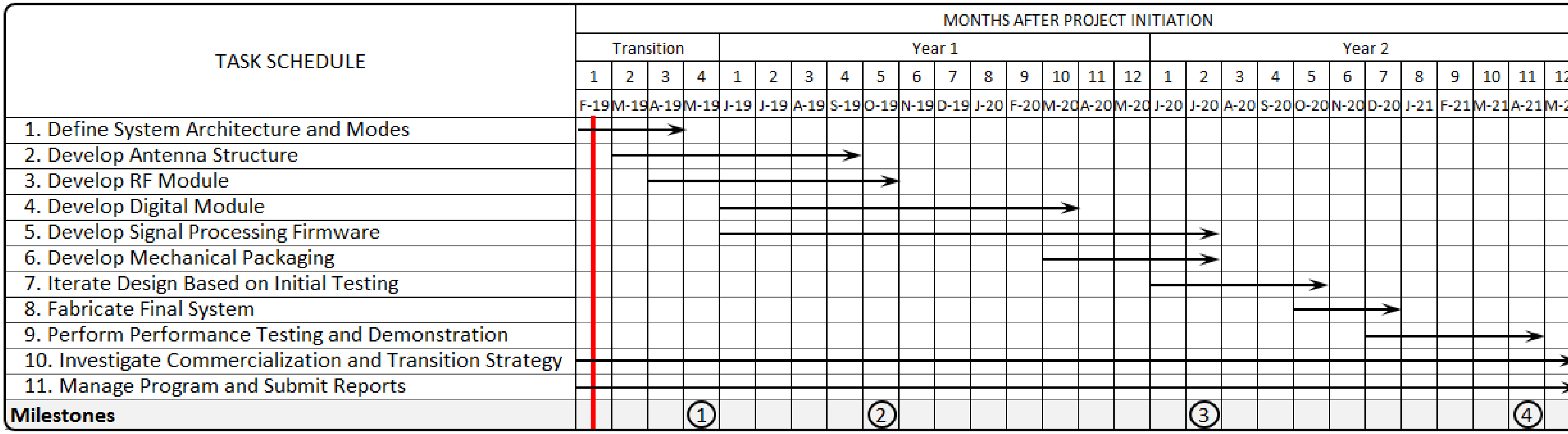
Phase II Performance Schedule



Milestone 1: Architecture and modes defined
Milestone 2: Initial RF system is comlete with initial test results.
Milestone 3: Initial integrated system is complete with initial test results.
Milestone 4: Prototype is demonstrated.

Base Period of Performance: 02/01/19 – 05/31/21
Funded Amount: $1,048,917

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ISI Solution

PAN-UAS system uses a new design that combines state-of-the-art high frame rate airspace monitoring technology utilizing the latest advances in radar, including

- digital beam-forming,
- all-digital scanning MIMO (multiple-inputs, multiple-outputs) radar,
- machine learning (ML) micro-Doppler analysis algorithm for rapid identification of small UAS targets.

PAN-UAS is able to automatically detect and counter multiple UAS targets through low-power, wide field-of-view scanning radar detection and wide-beam RF jammer that uses low duty cycle and narrow-band waveforms to achieve high peak power.

Ruggedized, integrated components and solar-powered batteries allow PAN-UAS to operate continuously outdoors in a wide variety of weather and atmospheric conditions.

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PAN-UAS Performance Parameters

Parameter	Phase II Threshold	Phase II Objective
Detection Range - Group 1 / Group 2	1.5 km / 4 km	2 km / 6 km
Tracking Range - Group 1 / Group 2	1 km / 3 km	1.5 km / 5 km
Range Resolution	1.5 m	1 m
FOV Azimuth / Elevation	100° / 100°	
Angular Accuracy at 1 km for RCS = 0.01 m^2	$<0.6^\circ$	$<0.4^\circ$
Cross-range Accuracy at 1 km for RCS = 0.01 m^2	$\pm$10 m	$\pm$7 m
Doppler Resolution	0.26 m/s	
Frame Time	0.1 s	
Frequency Band	5.6–5.8 GHz (C-band)	
Waveform	Fast FMCW	
Angular Scanning	2-D MIMO	
Size (W$\times$D$\times$H) cm^3	16$\times$30$\times$5 (147 in^3)	14.5$\times$27.6$\times$4 (98 in^3)
Weight, kg	1.2	1.0
Power Average Consumption, W	2.5	1.82
Estimated Production Cost	$14,000	$11,000

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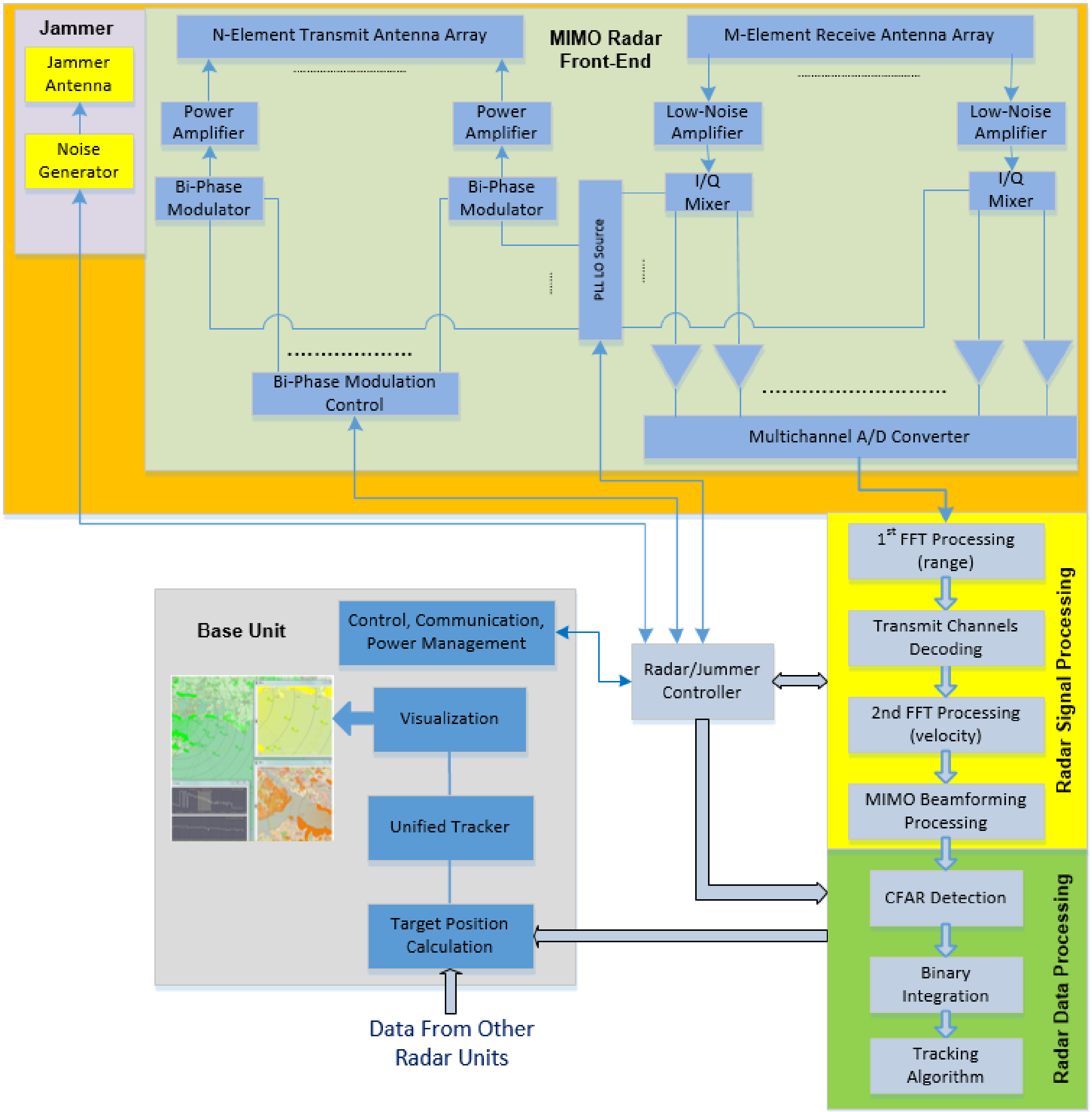
PAN-UAS Architecture



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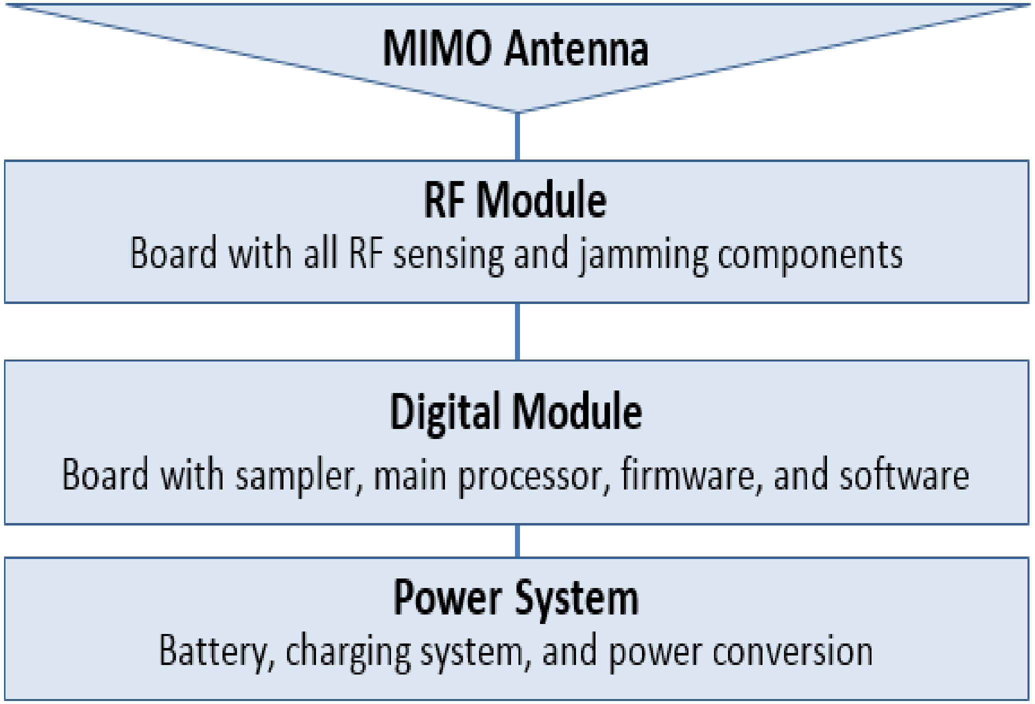
PAN-UAS – Main System Modules

- ISI will determine the essential modes and use cases for the PAN-UAS system and will ensure that the architecture covers all such cases.
- ISI will model and simulate operation of the main system components to optimize the system architecture and achieve required performance.



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Radar Frequency Band Selection

Based on in-depth analysis and simulation, ISI selected C-band for the PAN-UAS radar as providing the most compact and accurate UAS detection solution.

Parameter	S-Band	C-Band	Notes
Aperture Size	Marginal for Compact Radar System	Compact MIMO Configuration	Longer wavelength of S-Band forced us to apply MIMO design with very close distance between Tx and Rx antenna elements. The approach requires T/R leakage compensation and may result in antenna pattern distortion
MIMO Design Flexibility	Limited	Flexible	
Doppler Resolution for 0.1s coherent time	0.41 m/s	0.26 m/s	Doppler resolution is very critical for detection small USV in cluttered environment
Power Consumption	Low	Moderate	Larger receive antenna area allow lower power transmitters for S-band. The drawback of the C-band can be compensated by smart power management

Fast FMCW radars operating at higher frequencies (X-band, Ku-band, etc.) have range-Doppler ambiguity problems and high complexity of planar antenna aperture design. Lower frequencies do not allow for compact antenna design.

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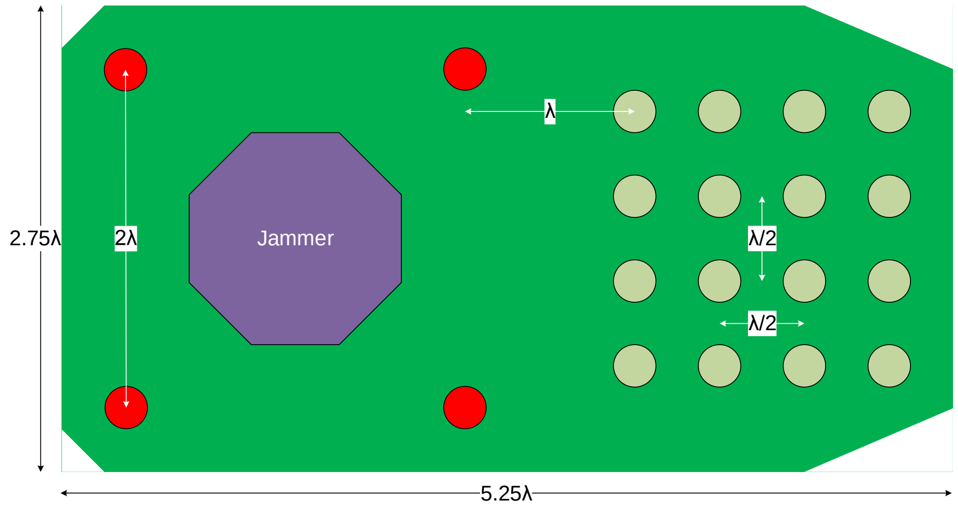
PAN-UAS Antenna

- ISI will develop a new 4x16MIMO antenna array with 64 virtual receive channels that achieve the same performance as a 64-element phased array, but at much lower power consumption and component cost by eliminating the need for phase shifters.
- The antenna will be implemented as a microstrip patch array.
- The antenna PCB also incorporates a wide-beam jamming antenna.



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RF Module

- PAN-UAS radar operates in C-band with carrier frequency 5.7 GHz and 100 MHz modulation bandwidth.
- PAN-UAS RF Module is integrated with the antenna with the RF components mounted on the opposite side of the antenna PCB.
- The RF Module design uses PCB vias as feeds for antenna elements to minimize signal losses.
- The RF module operates a fast FMCW radar that sweeps the transmit frequency while the received signal is mixed with the transmit waveform. To provide Doppler capability we will use multiple fast chirps instead of a single long chirp (slow ramp) in a conventional FMCW.
- ISI plans to use a 100 ms dwell (frame) time with 1024 chirps, each 97.7 µs long. Using a 100 MHz modulation bandwidth provides a 1.5 meter range resolution.

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Digital Module

- ISI will develop Digital Module that executes digital signal processing (DSP) algorithm, target identification and tracking, as well as system control functions.
- The embedded processor software includes the standard embedded stack with board-support package (BSP) and drivers, real-time operating system kernel, connectivity, audio/alarm, and a simple user interface.
- Digital Module also integrates the power management circuit and embedded software that enable continuous battery-powered operation for up-to 8 hours.
- The design of Digital Module will include a COTS SoM based on Xilinx MPSoC and a carrier board with power management and communication circuits.

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DSP Algorithm

- ISI will enhance its MIMO radar DSP algorithm to meet the PAN-UAS system requirements. This algorithm, developed in MATLAB®, implements the fast multi-chirp radar waveform.
- PAN-UAS will detect multiple stationary (like hovering quadcopters), slow, and fast moving (up to 200 m/s) UAS.
- We will explore the use of ML-based micro-Doppler signature analysis to discriminate small UAS from birds. This development will utilize ISI's expertise in neural networks and prior work on ML algorithms for Micro-Doppler signature analysis and target identification.

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DSP Algorithm (cont.)

Radar signal processing steps developed by ISI:

(a) Signal capture;

(b) MIMO processing – 64 channels;

(c) Range FFT;

(d) Doppler FFT;

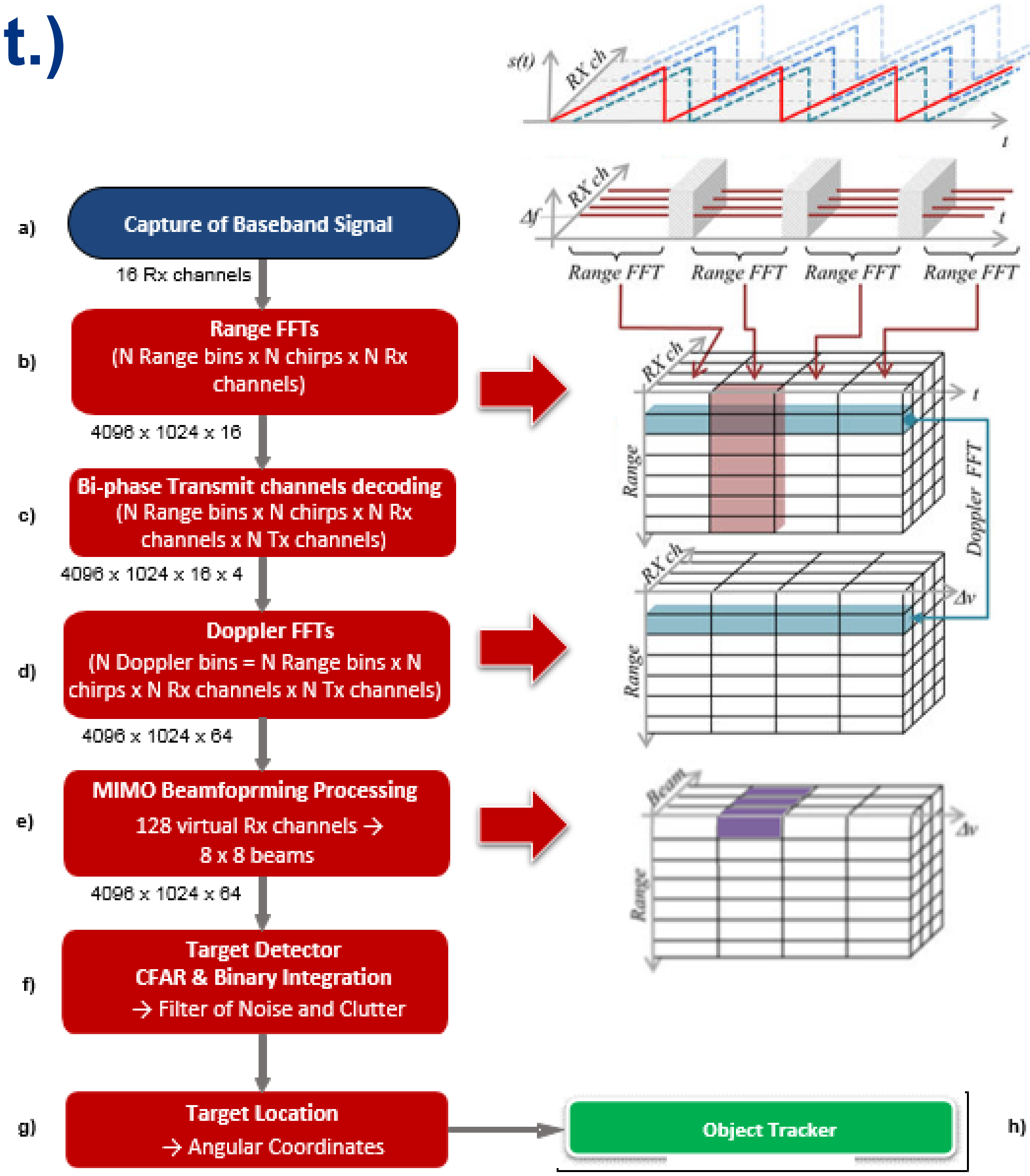
(e) Digital beamforming,

(f) Target detector;

(g) Target location;

(h) Object tracker.

The processing illustration shows only four RX channels for clarity.



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Tracking Algorithm and Control SW

- PAN-UAS uses the multiple-target tracking and identity management algorithm that incorporates a modified version of the approximate joint probabilistic data association algorithm for data association, the residual-mean interacting multiple model algorithm that uses a bank of Kalman filters for hybrid state estimation, and the multiple hypothesis testing algorithm for identity management. PAN-UAS tracking algorithm will be optimized to achieve the required computation throughput while handling 20+ small UAS targets.
- Digital Module that executes the DSP and tracking algorithms, also performs the system management functions including the power management that enables extending the battery operation beyond 24 hours without recharge. This is achieved by dynamic control of the power consumption by the RF and digital modules and by hierarchical power management scheme that includes sleep, stand-by, sentry, active, and jamming modes.

Mode	Power Consumption	Frequency of Use
Lo-Power Sentry	1 W	93.5%
Full-Rate Scanning	12 W	5.5%
Scanning and Jamming	21.9 W	1%
Weighted Average	**1.82 W**	

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Jammer

- PAN-UAS activates jammer when a UAS target is identified.
- Wide-band jamming targets communication and control channels and GPS frequencies using the following antennas:
  - 2.4 GHz – dedicated jammer antenna
  - 5.8 GHz – radar transmit antenna
  - GPS, GLONASS, and GALLILEO frequencies - dedicated jammer antenna
- Continuous jamming for >30 seconds causes most UAS to either land or return to their base.
- Jammer circuit is integrated with the RF Module.

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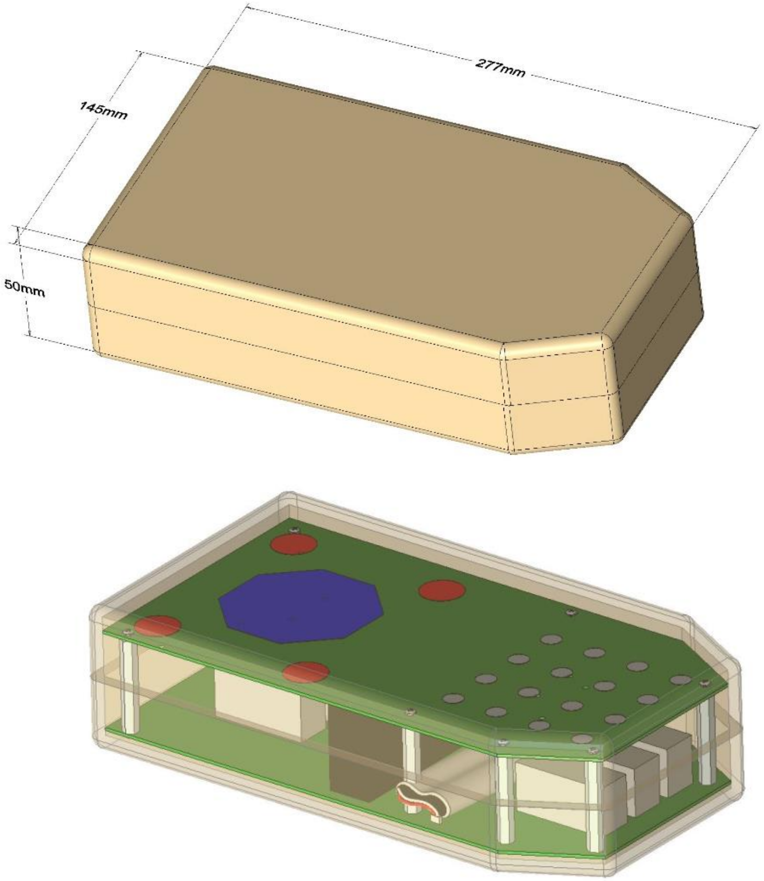
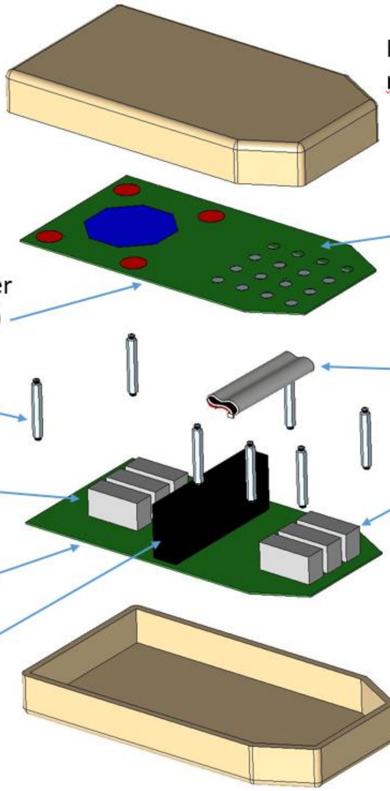
Mechanical Enclosure

- ISI will develop mechanical packaging for the PAN-UAS system to allow for unimpeded operation while meeting military standards for environmental ruggedness and electromagnetic compatibility. It will include batteries, USB-C connector for battery charging and connectivity, and a mounting support. PAN-UAS will provide a simple user interface consisting of a power switch, LED indicators (including operation mode and battery status), and an audio alarm.
- ISI will use aluminum housing and a composite material with low dielectric constant and loss tangent for the antenna cover to build a low-weight, hermetic, ultra-ruggedized, IP68 compliant packaging.

PAN-UAS Device Assembly





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System Development, Integration, and Testing

- ISI will apply its concurrent development methodology to the PAN-UAS project with iterative refining of the components' design and achieving full functionality of the system prototype.
- ISI will use incremental integration and test of electronic modules and software algorithms. This methodology optimizes the level of block/module testing before integration.
- Subsystem integration, including antenna and RF Module, DSP algorithm and Digital Module, Jammer and RF Module, will be thoroughly verified using dedicated test setups. We plan to use an external lab for antenna testing.
- The fully integrated prototype will be tested in ISI facility (indoor and outdoor) and a dedicated C-UAS test facility.

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PAN-UAS Prototype Test and Demonstration

- PAN-UAS prototype will be a fully integrated system. The test setup will include a host system that will receive the targets data and visualize them on a screen.
- ISI will test the PAN-UAS system prototype operation in the scenarios defined in the test plan and evaluate the system performance.
- The PAN-UAS ptototype operation will be demonstrated to the Army team in the location chosen by the Technical Monitor.

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Commercialization Strategy and Transition

Product Vision: PAN-UAS system will be a fully integrated, man-portable UAS protection system complete with a scanning radar system and active narrow-band jammer to disrupt both GPS and communication-and-control signals. The Phase III PAN-UAS system with a fully integrated power system and solar-powered battery will operate autonomously or with a host system. Estimated resale price of the PAN-UAS system is ≤$11,000 at moderate quantities.

Military Applications: PAN-UAS will be used for defending squad or platoon encampments from enemy UAS. This general anti-UAS capability will allow PAN-UAS to be a useful tool for all military branches that may wish to restrict airspace from UASs at a small, squad or platoon-sized level.

Transition: Transitioning the PAN-UAS device to Government markets will require progressive development to high TRLs through Phase II/IIE/III (TRL-5 by the end of Phase II) developments, following the successful development process ISI have used for a number of technologies. We will work to mature the technology while seeking development direction from potential end-users and identifying industry partners and additional funding sources for PAN-UAS development.

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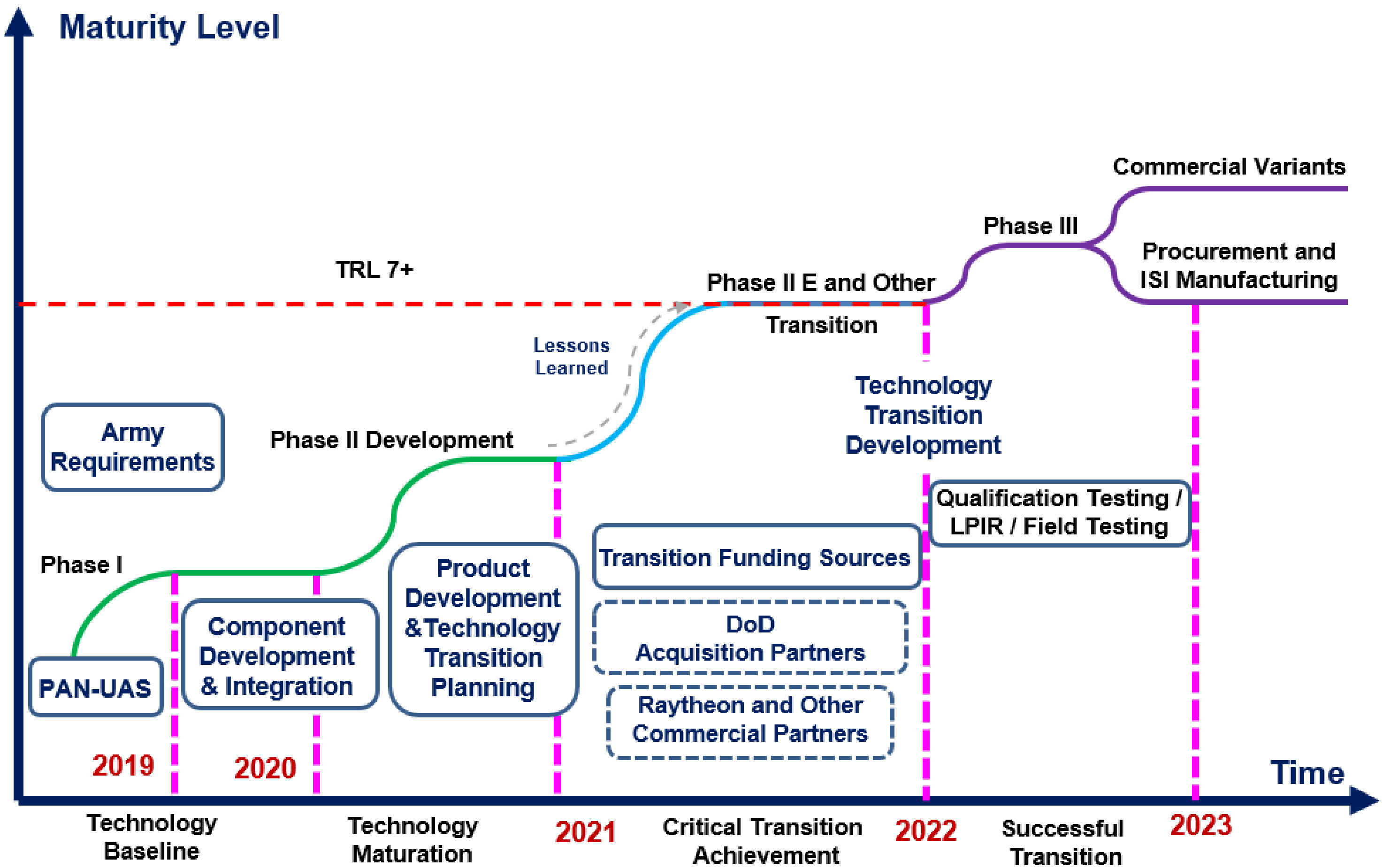
PAN-UAS Technology Roadmap



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Roadmap for the PAN-UAS technology depicting the growth in technology maturity from contract initiation to transition planning for the Phase IIE/III development.

Project Management and Deliverables

- Development and risk management
- Kickoff meeting
- Monthly progress reports
- Periodic discussions of the development and simulation/test results
- Final report presenting project achievements and recommended next steps
- Transition plan
- Close-up meeting

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ISI Team

- Alex Genusov – PI and PM
- Victor Khodos – Radar architecture, RF Module, and Jammer
- Garrett Newell – DSP algorithm
- Alex Kuyper – Tracking and ML algorithms
- David Gustavson – RF PCB
- Gregory Peng – Digital Module
- Jim Roberts – Embedded SW
- Richard Koziol – Mechanical enclosure
- Brandon Janca - Testing
- Dr. Min-Yi Shih – Overall project delivery
- Mark Thomson – Business development

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Agenda

1. ISI Background
2. PAN-UAS Program Objectives
3. Phase II Development Plan
4. PAN-UAS system architecture
5. Antenna and RF Module
6. Digital Module
7. DSP algorithm
8. Tracking algorithm and Control SW
9. Jammer
10. Mechanical enclosure
11. Test and demonstration of the PAN-UAS prototype
12. Commercialization and Program management
13. **Open Discussion**

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Discussion Topics

- CONOPS
- Host system
- Demonstration

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