Collision Avoidance Millimeter Wave Radar (CAMWAR)

Navy Topic N192-061

DoD SBIR Kick-off Meeting

November 13 , 2019

Period of Performance: 10/07/19 – 4/10/20

Presented To:	Presented By:
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Review of Navy Needs

- The Navy is seeking an ultra-low SWaP, minimal aperture, 360° coverage, high update rate collision avoidance system for both manned and unmanned aviation to avoid collisions with other aircraft and ground obstacles like buildings, trees, poles, and power wires.
- Operations under general degraded visual environment (DVE) weather conditions, such as fog, or in rotary wing related brown-out (in presence of dust/sand) and white-out conditions (in snow) are very hard and risky for airborne vehicles' pilots or operators (for unmanned system). Also, risk of collision with other aircrafts or drones is significantly higher in DVE conditions.
- Any high resolution optical and infrared (IR) devices, such as cameras and LIDAR systems, are subject to significant degradation due to their small wavelength compared to the size of obscurant particles. Existing radar systems are either bulky/heavy or have poor resolution/sensitivity. Furthermore, these radars can provide high frame rate only for a very limited field-of-view (FOV), which reduces probability of obstacle detection.

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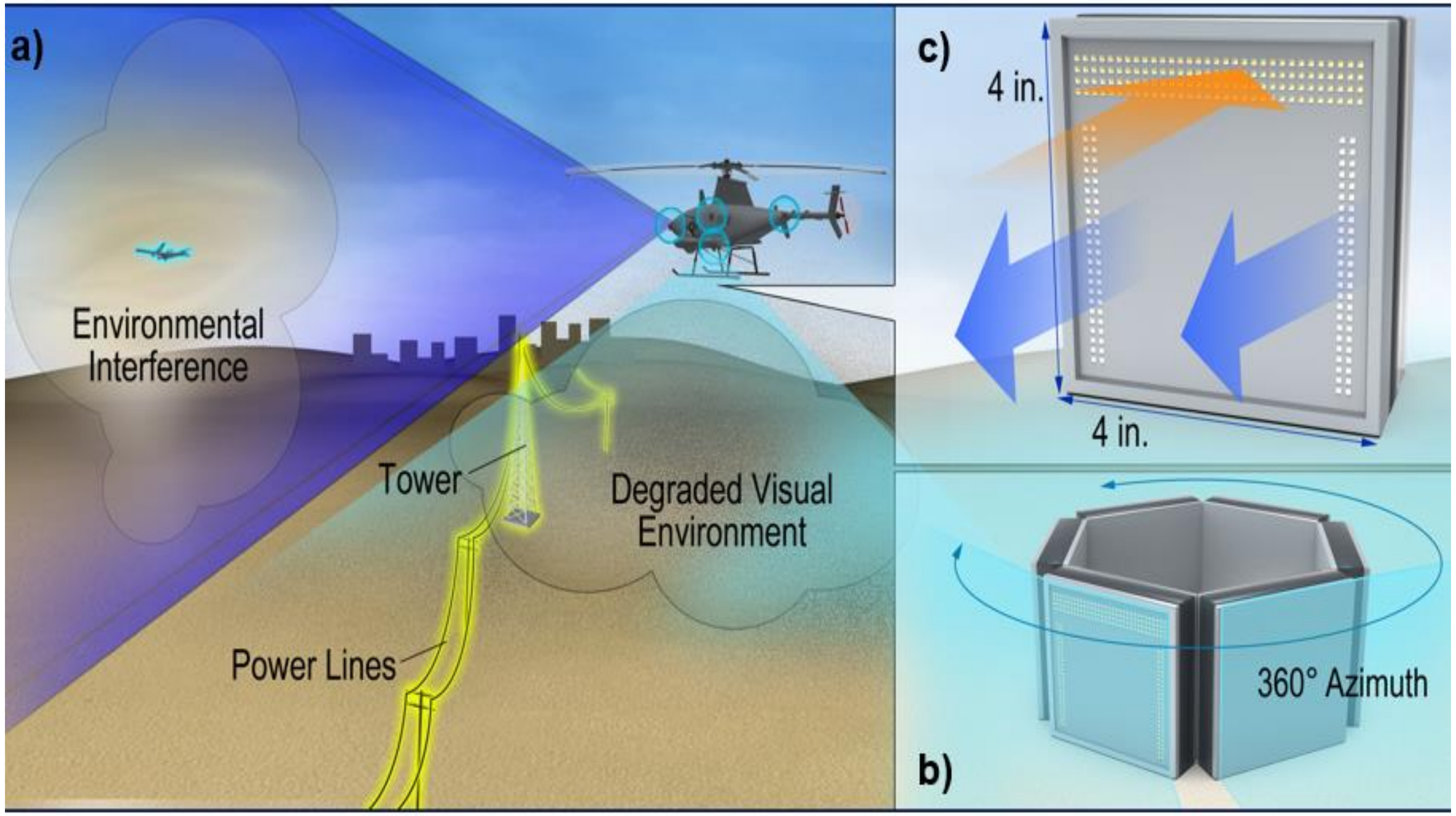
ISI's Solution: The CAMWAR



The CAMWAR system is specifically designed to fit airborne platforms including tactical unmanned aerial systems (UAS), to meet the SWaP and environmental requirements. It operates in E-band (76-81 GHz) and achieves 360° coverage in multiple (e.g. 6) radar sensor configuration with separate transmit and receive antenna arrays. A single radar sensor covers up to 90° in both azimuth and elevation. It combines analog and digital beamforming with a MIMO configuration, making a 100 Hz update rate possible through implementation of parallel operation and processing of multiple radar beams.

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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:

- **Ultra-low antenna aperture** and **highly integrated electronic components** enable compact implementation of a 360° CAMWAR radar system in a 200 $in.^3$ form factor that weighs <10 lb.
- **Very broad FOV** covers 360° in azimuth and up to 90° in elevation.
- **LPD/LPI operation** due to high time-bandwidth product FMCW waveform.
- **Extremely high 100 Hz update rate** due to DBF multi-beam parallel processing.
- **High Doppler resolution** due to long dwell and DBF parallel processing.
- **Low development, production, and maintenance cost** as well as low future obsolescence by using COTS components for automotive radars.
- **Modular scalable architecture allowing for easy adaptation** of the CAMWAR radar to new applications.

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Phase I Work Plan

Phase I Goals and Objectives

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

Phase I Objectives:

Objective 1. Development of a conceptual design of the CAMWAR system that addresses the Navy's needs.

Objective 2. Design and development of simulation models of the CAMWAR operation.

Objective 3. Develop a conceptual prototype. Simulation, analysis, and testing to demonstrate feasibility of the CAMWAR technology.

Objective 4. Definition of the commercial market for CAMWAR.

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Project Tasks

Task 1. ***Develop a Conceptual System Architecture (Objective 1)***

ISI will develop the concept system architecture for CAMWAR. Frequency band, antenna configuration, and modulation waveforms will be selected to satisfy the Navy requirements. ISI will validate the architecture through modeling and simulation.

Task 2. ***Develop a Model of the Radar Operation (Objectives 2)***

ISI will model and simulate the radar system's performance under various weather and DVE conditions and for different types of objects/obstacles to establish design requirements for the system components.

Task 3. ***Design and Develop a Radar Transceiver (Objectives 3)***

ISI will design a broadband mmWave multi-channel radar transceiver. ISI will analyze and select COTS components and optimize the design for low cost and SWaP. ISI will validate the transceiver design through modeling, simulations, and experiments.

Task 4. ***Design and Develop an Electronically Scanned Antenna (Objectives 3)***

ISI will develop a scalable 2-D linear array MIMO antenna configuration, which achieves the highest angular resolution in the limited aperture. The antenna will be modeled and simulated in ANSYS HFSS with the assistance of our consultant, Dr. Avakian.

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Project Tasks (cont.)

Task 5. ***Demonstrate Feasibility of CAMWAR (Objective 3)***

ISI will develop a conceptual prototype of the CAMWAR sensor. ISI will test and demonstrate the feasibility of the CAMWAR concept by simulating the system's behavior and performance under various conditions, analyzing design tradeoffs, and evaluating performance of the CAMWAR radar.

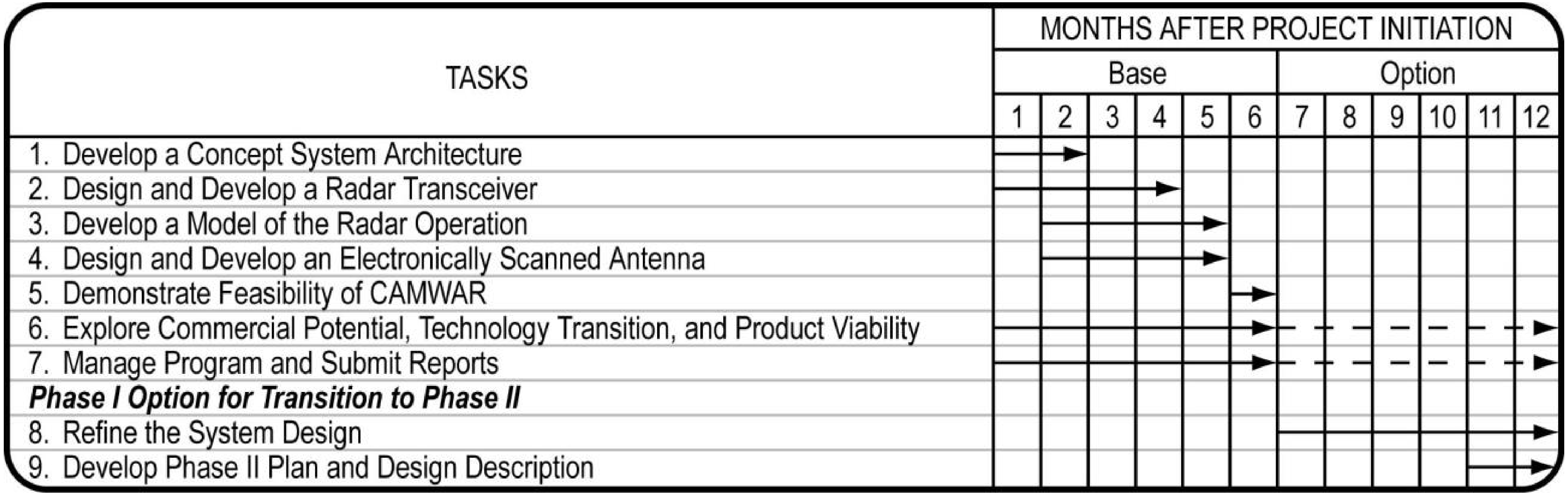
Task 6. ***Explore Commercial Potential, Technology Transition, and Product Viability (Objective 4)***

ISI will explore the potential to transfer CAMWAR to military systems and civilian applications. Market research will identify the most promising applications of the CAMWAR 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.

Performance Schedule



Period of Performance: 10/07/19 – 4/10/20

Funding: $139,998

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Technical Discussion

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Develop a Conceptual System Architecture (Task 1)

- Recent fast progress in development of the mmW radar technology is related with commercial market for automotive application, such as ADAS (advanced driver-assistance systems) and automotive auto-pilot systems. High integration level of the mmW chips developed by big electronic companies, e.g. Texas Instruments and NXP, allow significant SWaP-C reduction and open new opportunity for mmW radar designers. Also, recent advancement in digital technic made feasible new radar technologies such as MIMO and digital beamforming.
- ISI radar design approach will be based on utilization and combination of the newly available high integrated mmW radar chips and new digital radar technologies.
- Low size and cost of the mmW components allow cascading configuration of the multiple chips to build high angular resolution electronically steerable antenna arrays.
- Digital beamforming technic provides parallel receiving and processing of the multiple beams and allows very quick update time (10 ms) of wide (360°) radar FOV.
- MIMO radar configuration improve angular resolution in compact antenna aperture size.
- By following the commercial automotive systems radar development, the CAMWAR radar operates in 76-81 GHz.
- Since the RF power limitation of the mmW transmitters, FMCW modulation waveform has significant advantage over the pulsed one. To add Doppler capability to the FMCW operation, so called fast FMCW, or chirped modulation technic is developed. Also, all applicable 76-81 GHz high integrate transceivers are based on the fast FMCW. Thus, the fast FMCW waveform is selected for CAMWAR radar.

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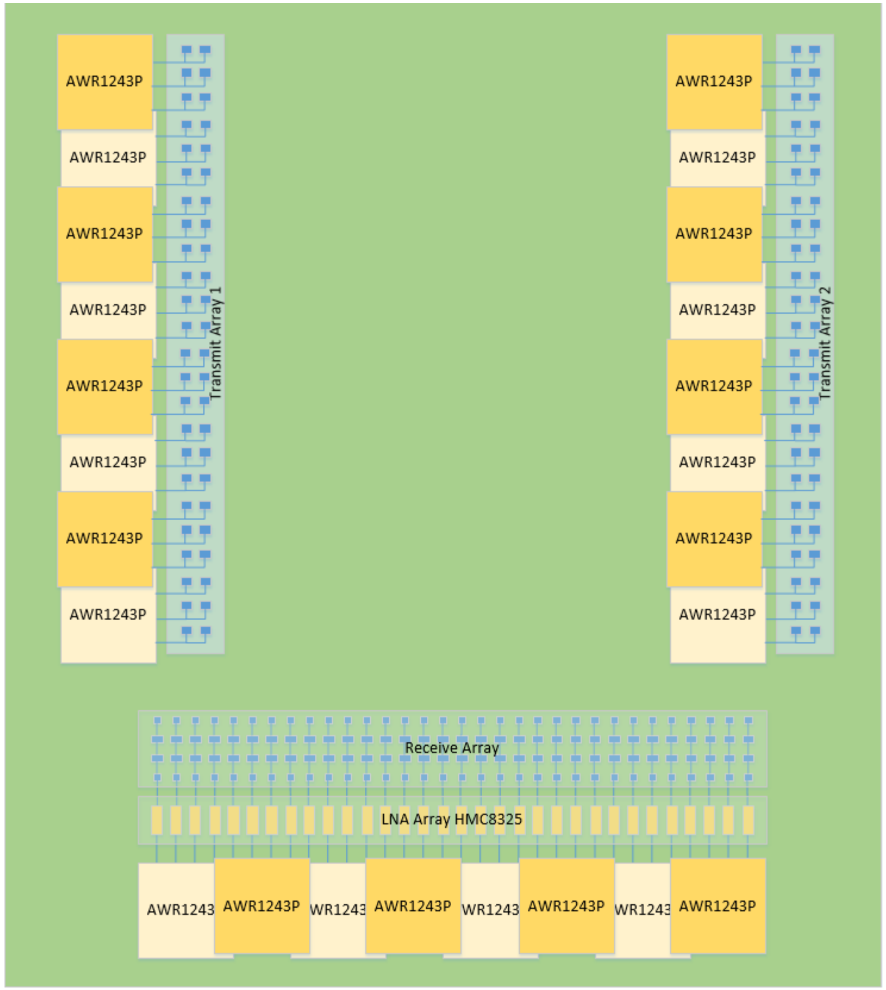
Develop a Conceptual System Architecture (Task 1) (cont.)



- As our analysis shows, despite recent progress in mmW technology, the most critical limitation for high resolution 2-D electronically steerable radar system is the power consumption and thermal conditioning of radar panels. This constraint is caused by high density of the phased array planar arrangement and low power efficiency in mmWave band.
- To achieve a high 2-D angular resolution with an acceptable power consumption under form factor constraints, we selected the CAMWAR antenna configuration that comprises separate transmit and receive linear (1-D) arrays with mutual orthogonality of the array orientation.
- Using two transmit arrays results in an effective doubling of the receive array length and improved radar resolution in azimuth direction.
- Both transmit arrays operate in analog beamforming (phased array) mode, while receive array provides digital beamforming operation, i.e. all the receive channels are down-converted, digitized, and processed in parallel.

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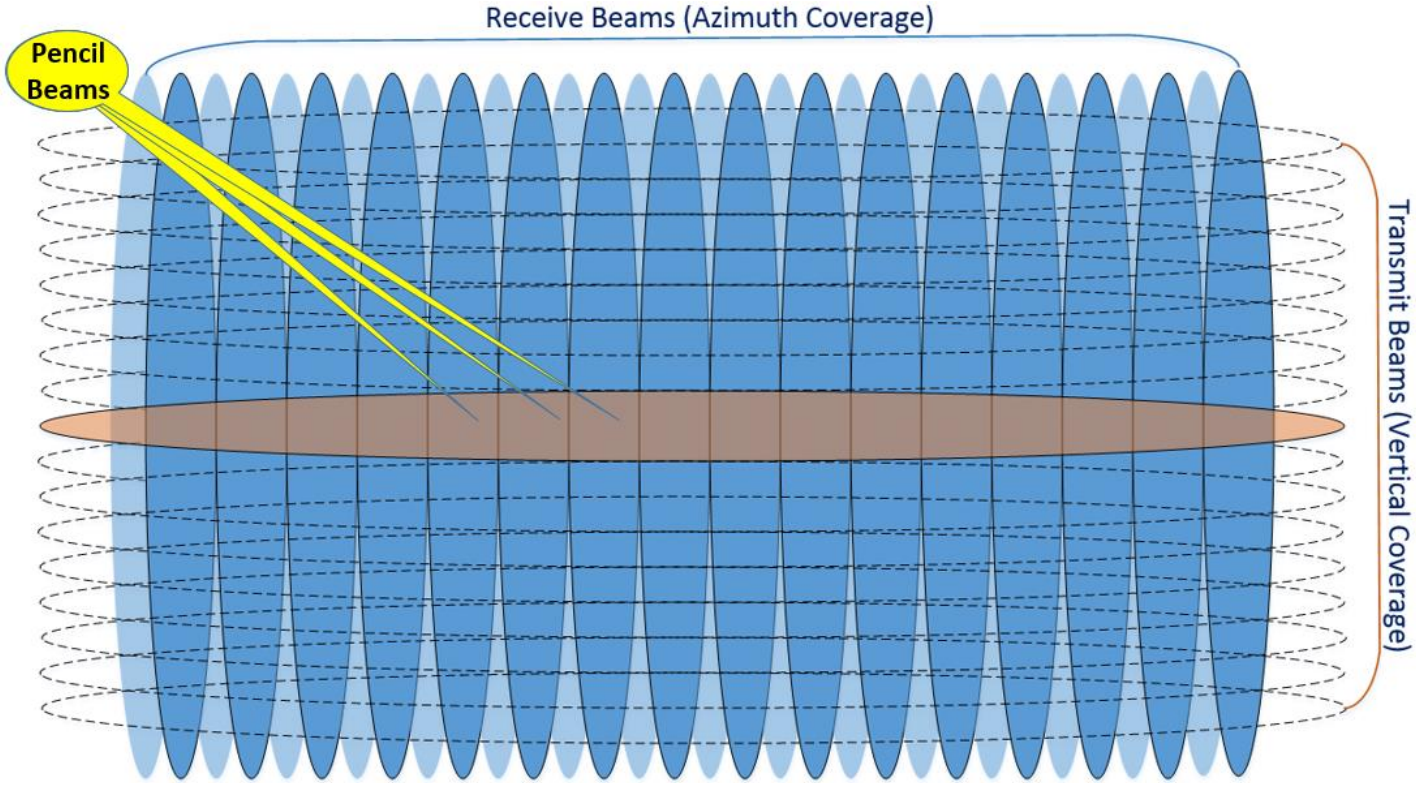
Develop a Conceptual System Architecture (Task 1) (cont.)



- The radar produces two orthogonal fan-beams:
  a) a transmit beam that is wide in azimuth and narrow and steerable in elevation, and
  b) multiple receive beams, wide in elevation and narrow in azimuth, that are produced in parallel by digital beamforming.
- The crossing area of these beams creates a pencil-beam equivalent of a radar two-way operation.
- The multi-beam parallel processing of receive signals by digital beamforming avoids wasting of transmit energy if analog beamforming of a pair of crossing orthogonal beams is used.
- The expected two-way angular resolution is 2° in azimuth and 4° in elevation.

Additional improvement in azimuth resolution may be obtained by using Doppler beam sharpening (DBS) technique. The DBS is applicable for side-looking directions of the moving platform. The azimuth resolution with DBS is limited practically by the time of operation and radar velocity and can reach 0.5° for 10ms radar frame and 50 m/s velocity of the radar platform.

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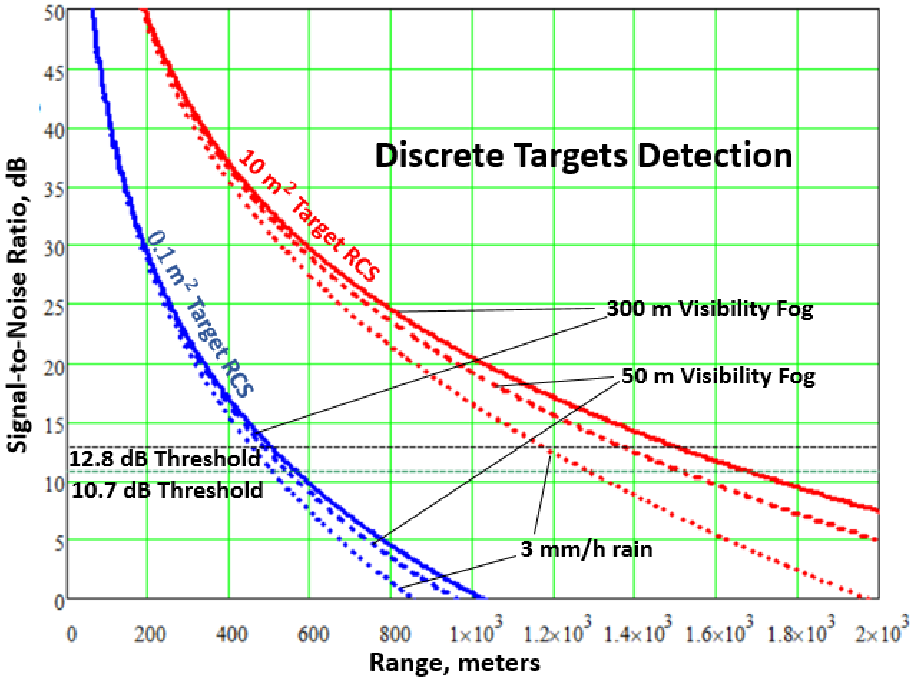
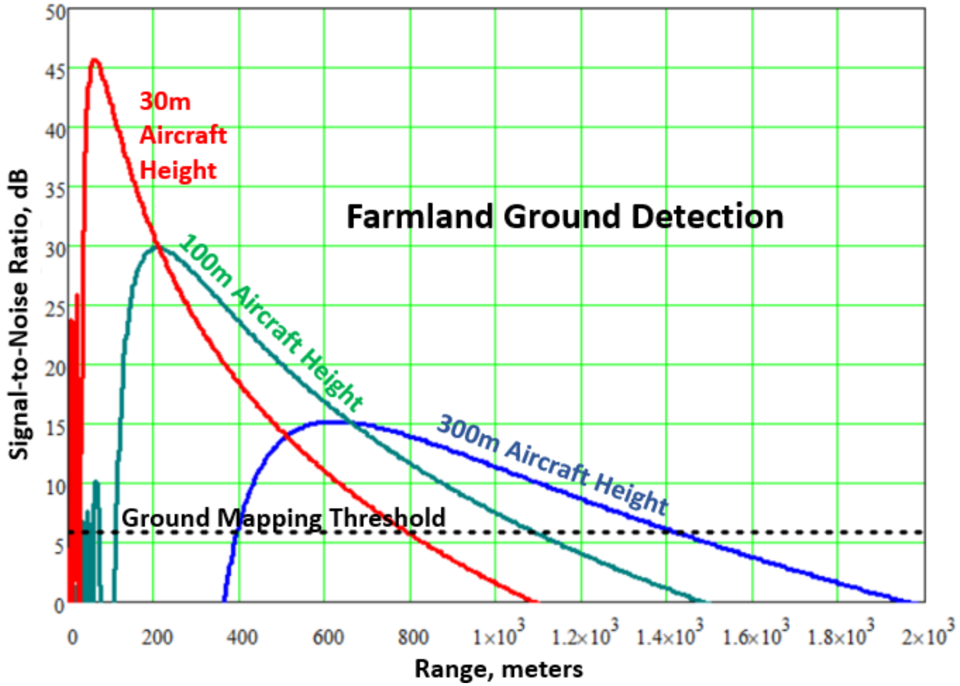
Develop a Model of the Radar Operation (Task 2)

- Preliminary Mathcad simulation of CAMWAR performance demonstrates that the radar can detect moderate size targets, such as a car, at the range of ≤2 km and detect power wires up to 600 meters away. The simulation also shows that radar can operate in light rain within a shorter but still acceptable detection range.
- To verify our radar concept we plan to build a detailed radar functional model in MATLAB. The model will include different environmental scenes, typical for a airborne radar platform, with discrete and distributed objects/obstacles (such as poles, wires, cars, trees, ground, road, etc.) with different reflectivity. Realistic antenna gain and resolution, as result of the HFSS simulation, will be applied to obtain a radar image of the scene. Various weather and DVE conditions (rain, fog, brownout) will be simulated to evaluate not only the radar signal attenuation, but also the clutter effect on the radar image.





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Design and Develop a Radar Transceiver (Task 3)

- Based on latest information from mmW electronic market we selected AWR1243P integrated 76-81 GHz radar transceiver from Texas Instruments (TI) as the main building block of the CAMWAR radar system. Besides the standard functions supported by other single-chip automotive radars from TI and NXP, such as 3 transmit and 4 receive channels with full up/down-conversion and baseband circuitry, a flexible modulation control with an embedded PLL synthesizer, multiple A/D converters, and a high-speed digital interface, AWR1243P includes fine 6-bit individual phase control of the transmit channels and multi-chip cascading capability.
- The low cost integrated mmW radar chips have some drawbacks and limitations, and a proper design solutions should be found for CAMWAR transceiver configuration to address these issues. Here are the some of the problems to be resolved and how we plan to do it:
  - Poor phase noise performance of the LO signal in AWR1243P. We plan to apply external 19-20 GHz PLL synthesizer as LO source for all the radar chips.
  - Maximum number of cascaded AWR1243P chips is four. We will develop active distribution circuits for the LO, clock, and synchronization signals to increase the number of cascaded chips to 24.
  - Poor noise figure (NF=14 dB) of the receiver channels. We will add external LNAs with to reduce NF to 4 dB.
  - In a standard usage mode, AWR1243P radar simultaneously operates the transmitter and receiver. We will use AWR1234P in either transmit or receive mode to enable placing the radar device next to the antenna section it controls. We will also investigate the ways to minimize power consumption of AWR1243P and CAMWAR radar.

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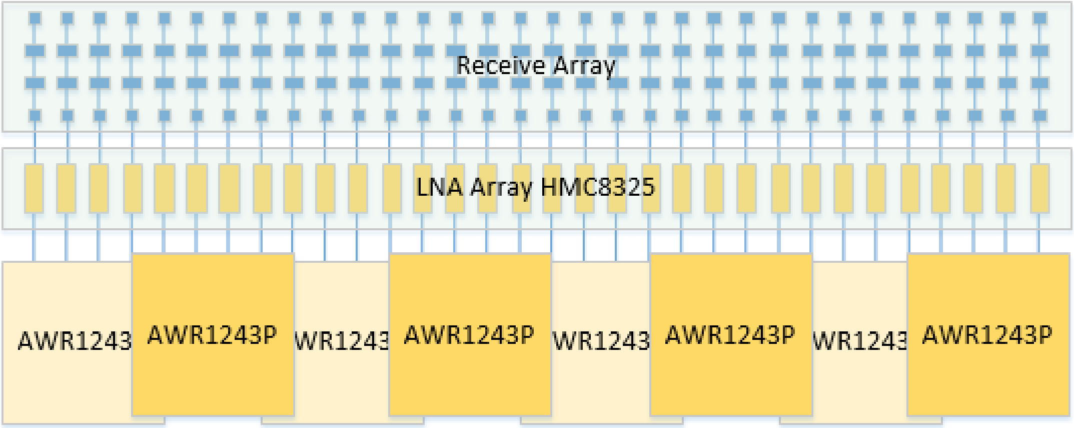
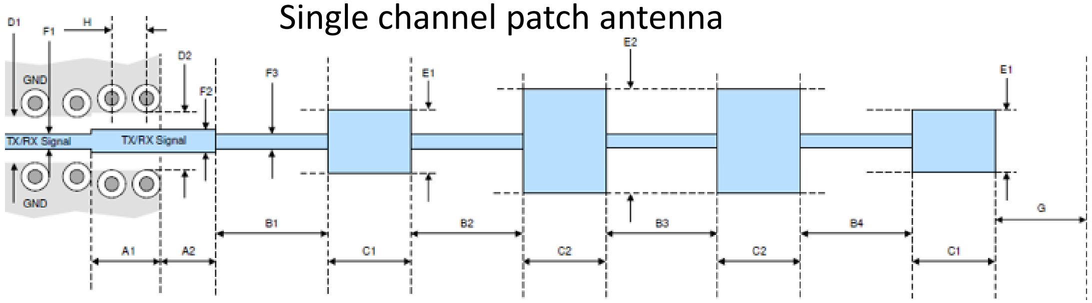
Design and Develop an Electronically Scanned Antenna (Task 4)

During Phase I of the CAMWAR project, ISI will design the receive and transmit antenna elements and arrays by using 3-D electromagnetic field simulator HFSS with the assistance of our consultant, Dr. Avakian. Antenna beam patterns and gain values calculated with HFSS will allow to refine the CAMWAR radar parameters and verify the radar performance using the MATLAB model. The detailed antenna design with mechanical drawing and material definitions is an important step in the CAMWAR prototype design that will simplify the Phase II prototype development.

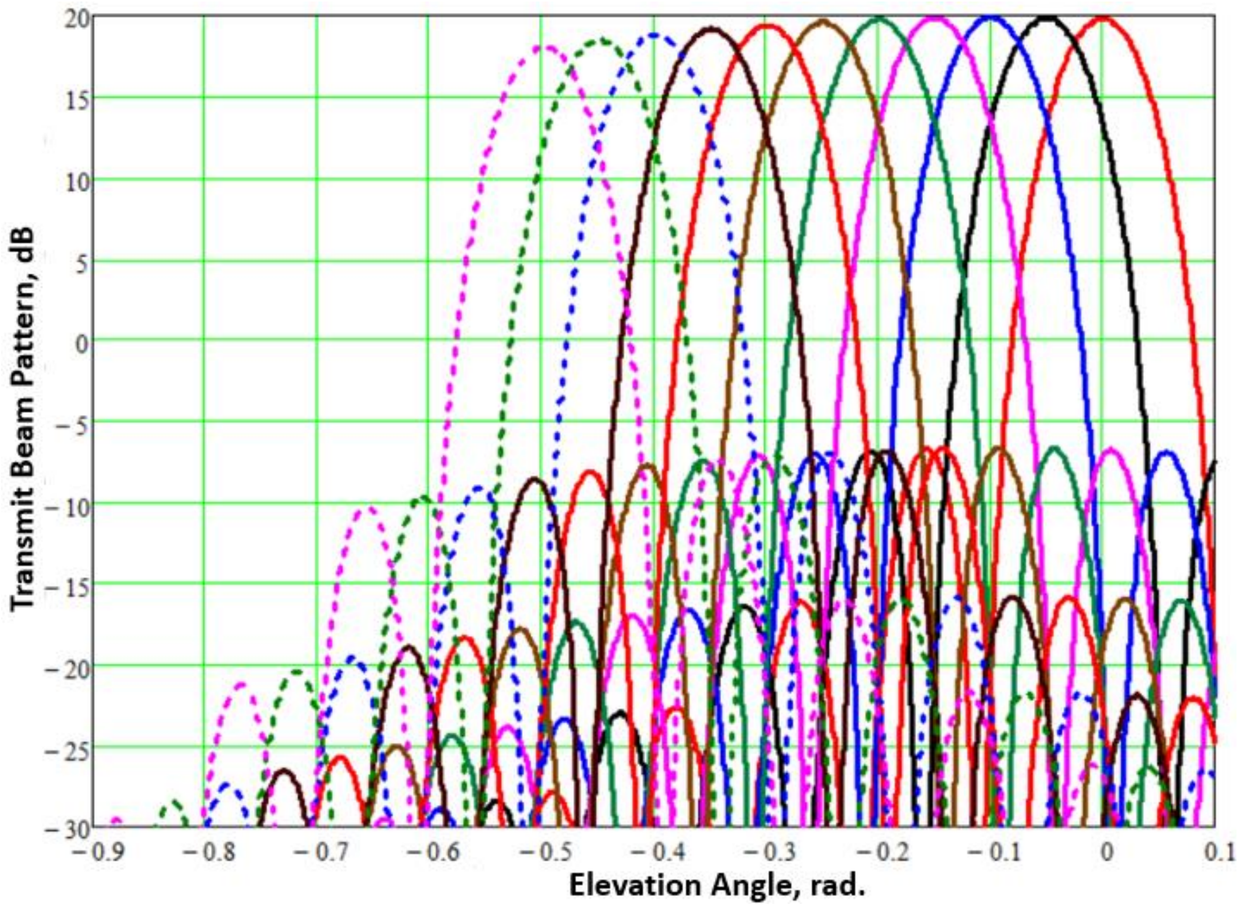
The receive array has 32 independent channels connected to 8 AWR1243P mmW radar devices that work in parallel on digital beamforming processing. The virtual receiver array with 64 channels is twice as large as the physical array. It provides ≤2 degrees azimuth resolution with the digital beamforming. The vertical beam of the receive array is fixed, 30 degrees width and tilted 10 degrees downward relative to the boresight direction. Digital beamforming allows for flexible tapering to suppress azimuth sidelobes.



Single channel patch antenna



Design and Develop an Electronically Scanned Antenna (Task 4)(cont.)



The transmit antenna contains two identical 24-channel arrays with 8 AWR1243P mmW radar chips in each array. Both transmit arrays are used in analog beamforming (phased array) mode. AWR1243P includes 6-bit phase shifters with a 5.6-degree step for each of three RF outputs connected to the antenna. The chip size of 10.4×10.4 sq. mm makes PCB routing very challenging for λ/2 (1.95 mm) pitch of a multi-element cascading array. We will increase the spacing to 2.5-3.0 mm and suppress the grating lobes (caused by >λ/2 spacing) by using an optimized antenna element pattern. To reach low vertical sidelobes (≤-25 dB) an accurate amplitude tapering will be implemented in the transmit array design.

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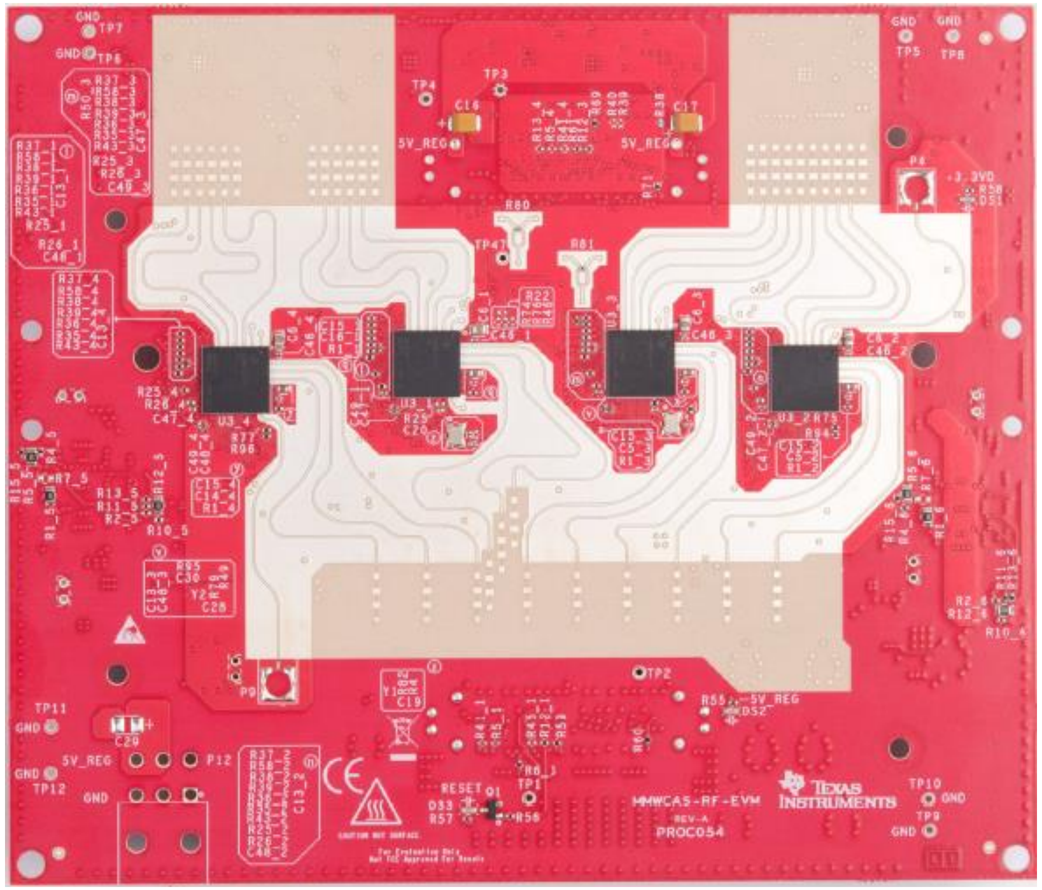
Demonstrate Feasibility of CAMWAR (Task 5)



- Likely accidentally, but meaningfully, the first commercial mmW imaging radar became available on the day of CAMWAR project start: 10/07/2019. The new evaluation module from TI (TIDEP-01012) provides the 350 m detection range (for a car size target), 70 degrees FOV, and 1.4 degrees angular resolution in azimuth direction by using four cascaded AWR1243P devices. Although, the TIDEP-01012 module has multiple drawbacks in comparison with the CAMWAR design (e.g. no vertical resolution, high RF losses, high noise figure and phase noises), it allows us at low cost to conduct experiments with cascaded configuration of mmW radar devices. We already procured this module and will be testing its operation outdoors.
- ISI will also demonstrate the CAMWAR concept feasibility by developing a detailed MATLAB model and simulating the radar operation under various conditions.
- We will compare the test and simulation results, analyze the design tradeoffs, evaluate performance of the CAMWAR radar, and identify possible improvements that will be addressed in Phase I Option.

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Project Team

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RF circuits and antennas

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

Sean Holloway, Research Engineer
Modeling and simulation

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

Major Ben J. Self, USAF (Sep.), Director, Business Development
Commercialization and technology transition

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Commercialization Strategy and Transition

- **Product Vision.** CAMWAR radar will be installed on airborne platforms and used for collision avoidance under DVE conditions. The compact mmWave MIMO radar sensor will fit into 4×4×2 in.^{3} form factor, weigh <10 lb, and consume <50 W of power during operation. The CAMWAR system will be capable of detecting with up to centimeter-level resolution ground obstacles like large rocks, power wires, trees, buildings, and other aircraft, covering 360° FOV in azimuth (in quad-sensor or hexa-sensor configuration) and 90° in elevation at up to 2 km range. Complemented with EO imaging system and EO/radar data fusion, CAMWAR will be able to provide an accurate composite view of the scene.
- **Target Military/Government Applications.** CAMWAR's primary application is SAA sensor solutions for tactical UAS, helicopters, and other airborne platforms. Additional military/government applications for CAMWAR radar include a landing system augmentation solution, a close proximity formation flying solution, and ground manned and unmanned vehicles for autonomous operation and/or in DVE. CAMWAR will be adapted for security and surveillance applications that can benefit from a compact high-resolution detection system.
- **Transition to Military Markets.** We believe that the key to transitioning will be the engagement of the program office and prime contractors, Lockheed Martin and Raytheon, early in Phases I/II, to design CAMWAR to meet platform requirements. We expect to produce a Phase II prototype that is ready for qualification in Phases IIE/III. ISI's manufacturing department will help in design for manufacturing reviews to facilitate a rapid transition to production.

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Project Management and Deliverables

- Development and risk management
- Kickoff meeting
- Monthly reports
- Periodic discussions of the development and simulation/test results
- Final report presenting project achievements, recommended next steps, and prototype development plans
- Initial Phase II Proposal
- Close-up meeting

- **Q&A**