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Multichannel Sense-and-Avoid Radar for Small UAVs

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Researchers

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On-campus technical support

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Outline

- The innovation

  Problem statement / Solution requirements

- Technical approach

  System overview / Theory / Implementation / Performance

- Impact of the innovation if it is eventually implemented
- Results of the LEARN Phase I effort to date

  Accomplishments / Findings / Schedule status

- Distribution/Dissemination—getting the word out

  32nd DASC (Digital Avionics Systems Conference) IEEE & AIAA

- Next steps

The innovation

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- Problem statement

  Small unmanned aerial vehicles (UAVs) may have a bright future in the commercial and industrial service sector.

  - Pipeline surveillance, agricultural surveys, road traffic monitoring

  Unacceptable risks result from the UAV's of lack situation awareness.

  - Hazard to both ground-based and airborne assets.
  - August 17, 2011 collision between U.S. Air Force C-130 cargo plane and an RQ-7 Shadow UAV over Afghanistan.

  Integration into the NAS requires compatibility with existing systems (e.g., transponder-based collision avoidance) as well as avoidance of non-cooperative objects (e.g., towers, balloons).

The innovation

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- Solution requirements

  Using programmable radar-ready integrated circuits, provide small UAVs with situation awareness by remotely sensing nearby objects and reporting their positions and closing rates to on-board guidance system.

Platform – 40%-scale Yak-54 RC aircraft

Key specifications

wingspan 3.1 m; length 3.1 m; payload 4 kg;
empty weight 18.1 kg ; cruise speed 36 m/s

Sensor requirements (from AE analysis*)

Key requirements

detection range 300 to 800 m;
range accuracy 10 m; range-rate resolution 1 m/s;
Doppler accuracy 10 Hz; update rate 10 Hz;
field of view 360° in azimuth, ±15° in elevation; angular accuracy 3°

* Stastny TJ; Garcia G; Keshmiri S; "Collision and Obstacle Avoidance in Unmanned Aerial Systems Using Morphing Potential Field Navigation and Nonlinear Model Predictive Control," *ASME Journal of Dynamic Systems, Measurement and Control*, Under Review, July 2013.

Technical approach

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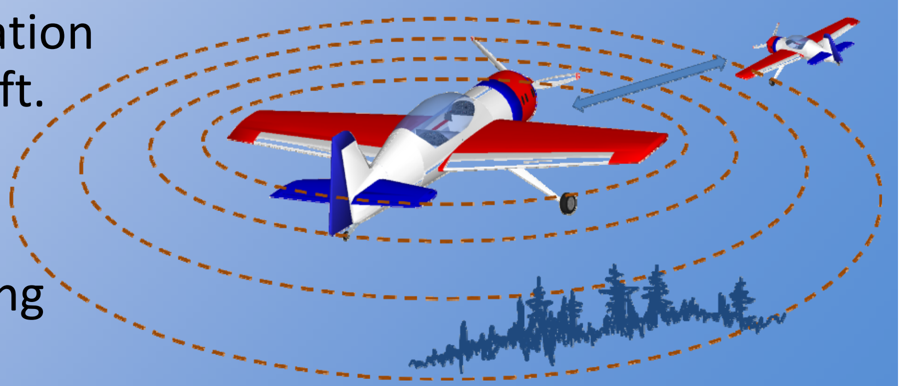
- System overview
  - Microwave radar provides all-weather, day/night detection and ranging capability of non-cooperative objects.
  - Frequency-modulated continuous-wave (FMCW) operation reduces transmit power requirements for measurement of range and radial velocities (via Doppler processing).
  - Multichannel system enables relative position knowledge in 3-D.

Phase I scope

Proof-of-concept demonstration aboard Cessna-172 for performance evaluation using 40% Yak-54 as intruder aircraft.

Phase II scope

Miniaturized version for flight testing on 40% Yak-54.



Technical approach

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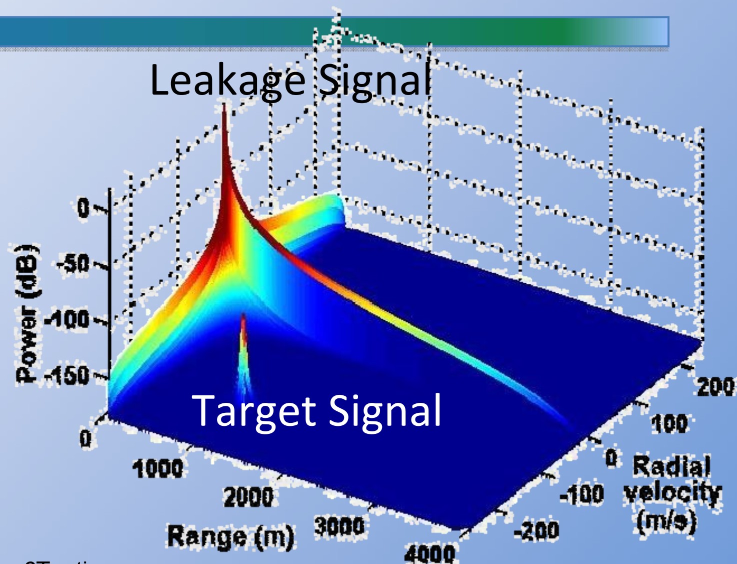
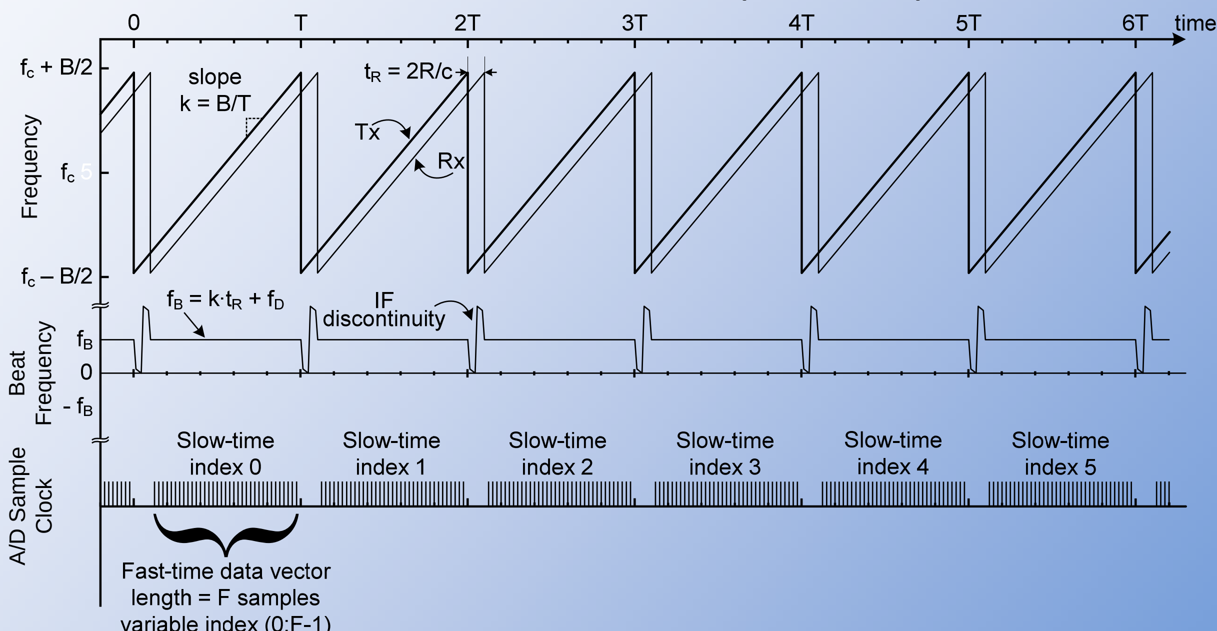
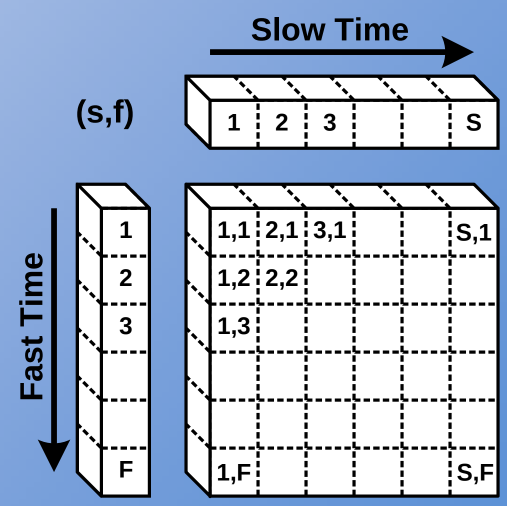
- Theory

  To overcome the challenge of strong Tx-Rx coupling, signals from targets near zero in both range and Doppler are ignored to permit reliable target detection. Signal processing involves 2-D fast Fourier transform (2-D FFT).

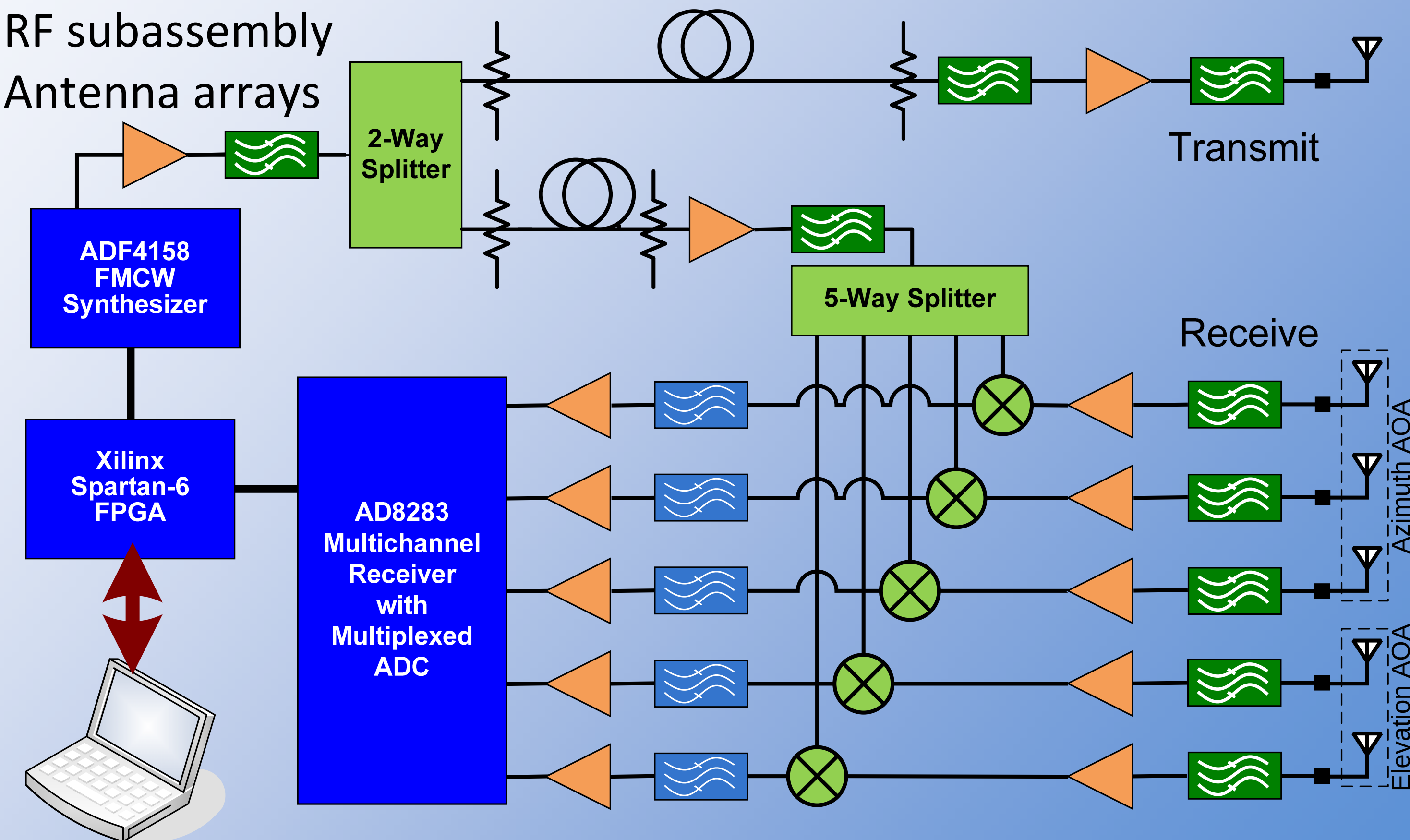






Technical approach

- Implementation – radar block diagram
  - Radar-ready ICs: FMCW synthesizer & multichannel ADC
  - FPGA
  - RF subassembly
  - Antenna arrays



Technical approach

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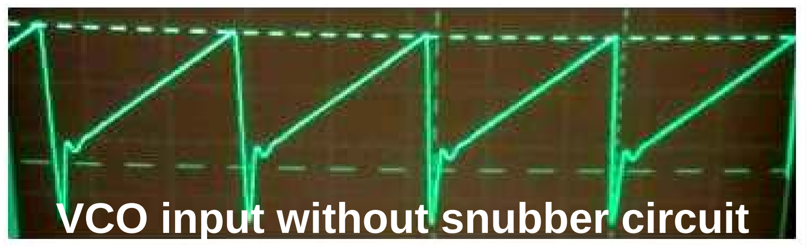
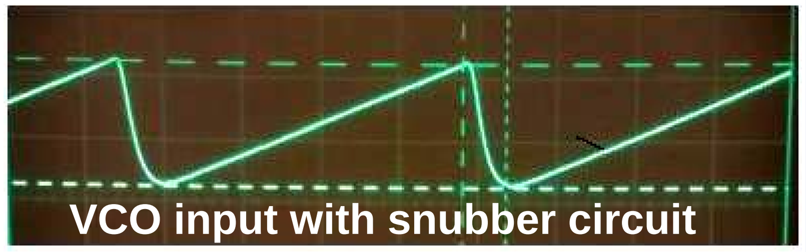
- Implementation – radar-ready subsystems

FMCW synthesizer

Analog Devices ADF4158

- ➢ FMCW signal generation
- ➢ Center frequency: 1.445 GHz
- ➢ Bandwidth: 15 MHz
- ➢ Modified evaluation board





Technical approach

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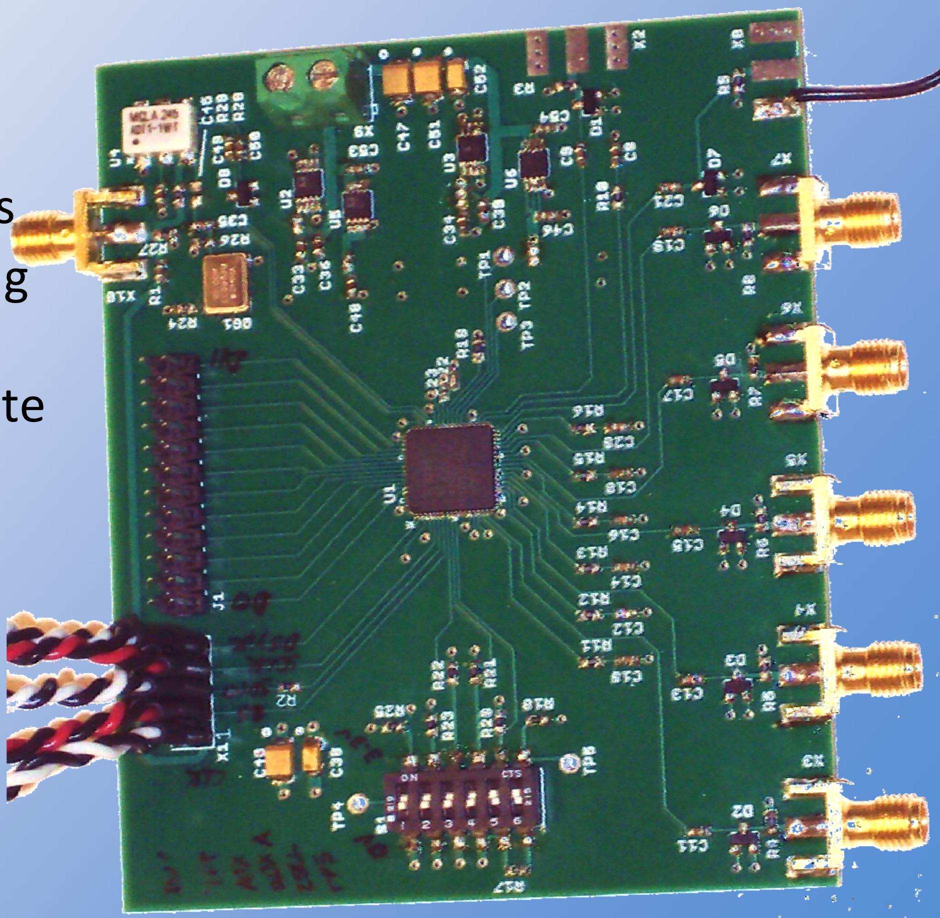
- Implementation – radar-ready subsystems

multichannel ADC with analog preprocessing

Analog Devices AD8283

- ➢ Custom PC board developed
- ➢ Up to 6 multiplexed analog channels
- ➢ Integrated analog signal conditioning via programmable LNA, PGA, AAF
- ➢ Operated at 4 MSa/s per channel rate



Technical approach

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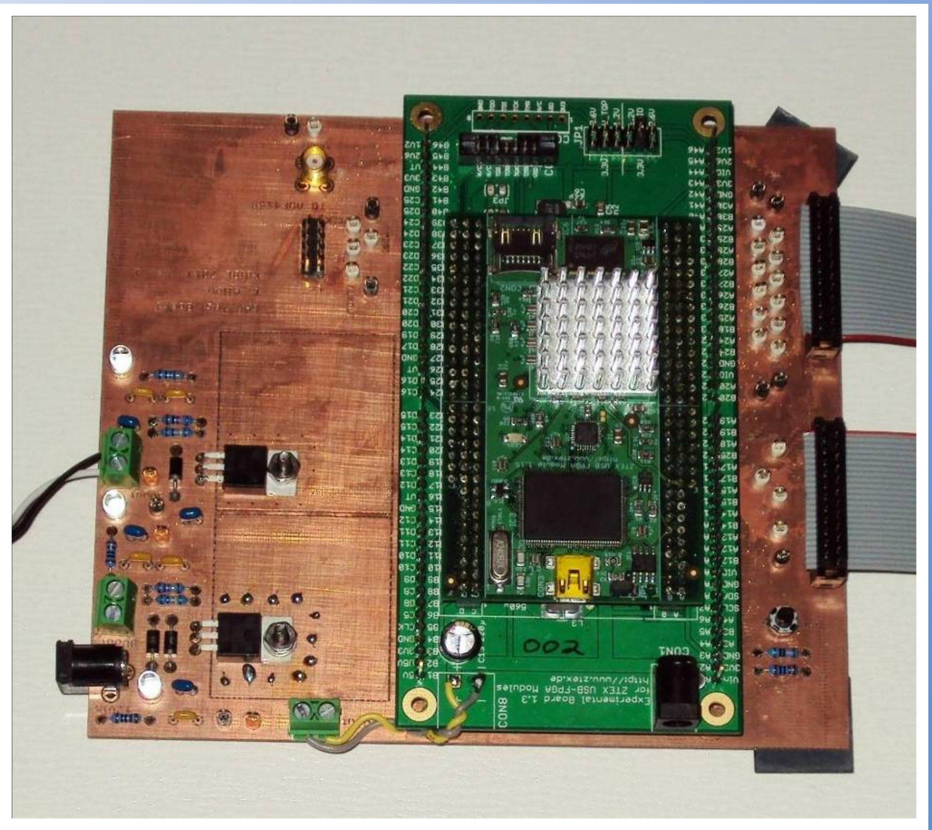
- Implementation – FPGA

field-programmable gate array

Xilinx Spartan 6

- Data windowing
- Radar timing and synchronization
- 1-D FFT (eventually 2-D FFT)
- Target detection
- Client communication

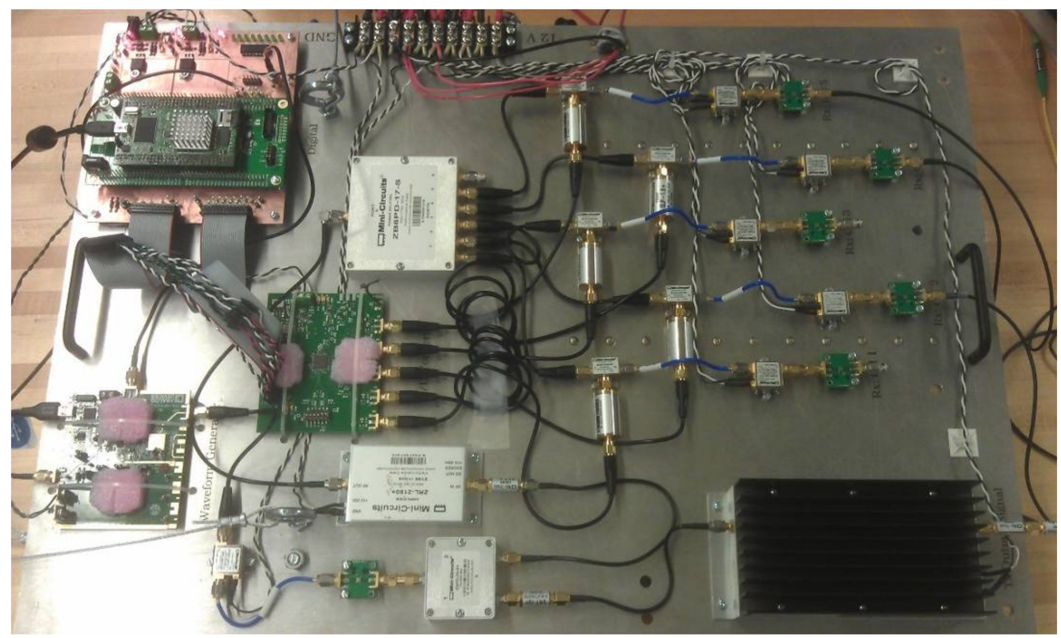


Technical approach

- Implementation – RF subassembly

RF subassembly

- One transmit channel
- Transmit power ~ 0.5 W
- Five receive channels
- Receiver noise figure 3.5 dB
- Receiver gain 64 dB



Technical approach

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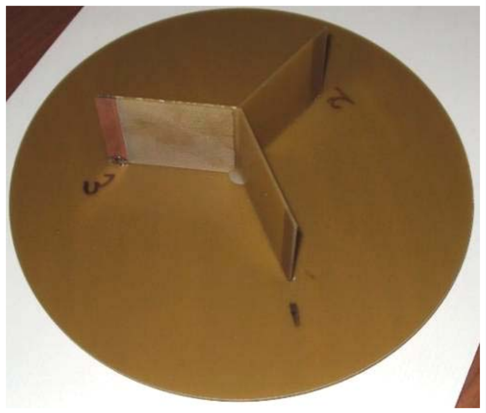
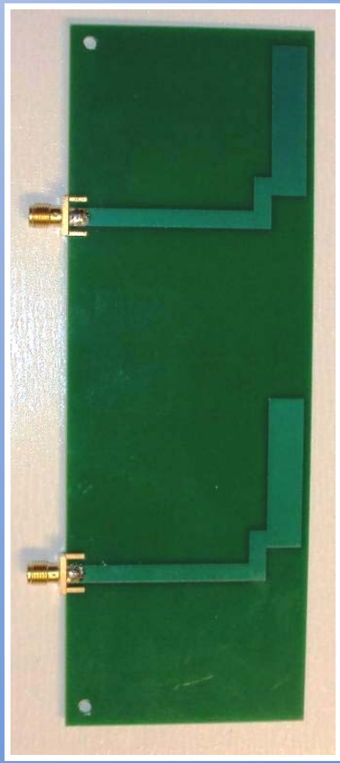
- Implementation – antenna arrays

Two receive antenna arrays

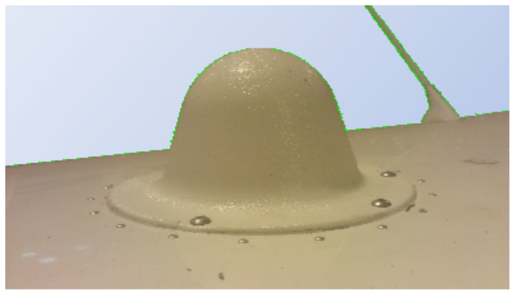
- Custom designs
- 3-element monopole for azimuth
- 2-element dipole for elevation





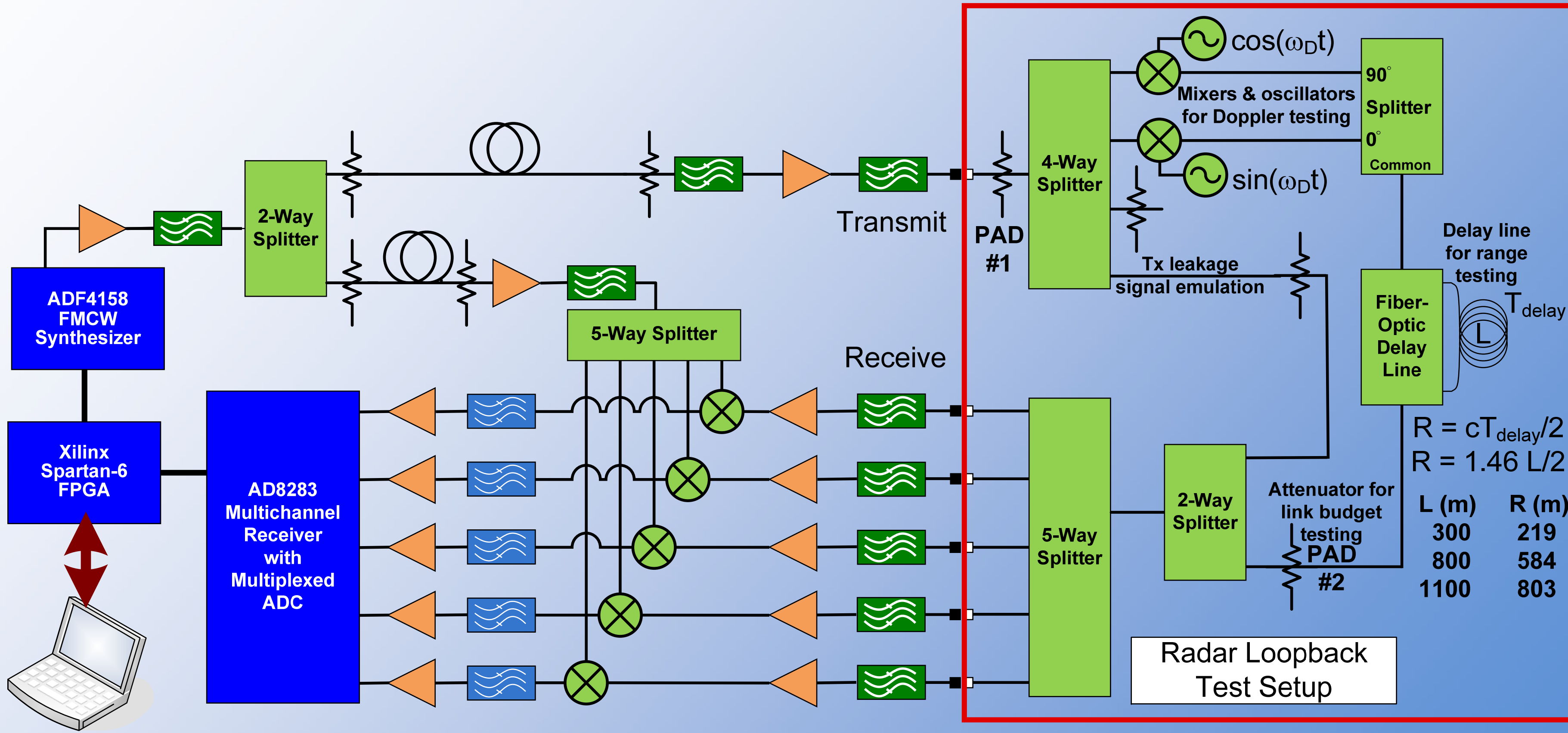
One COTS transmit antenna

- Pasternack PE51057



Technical approach

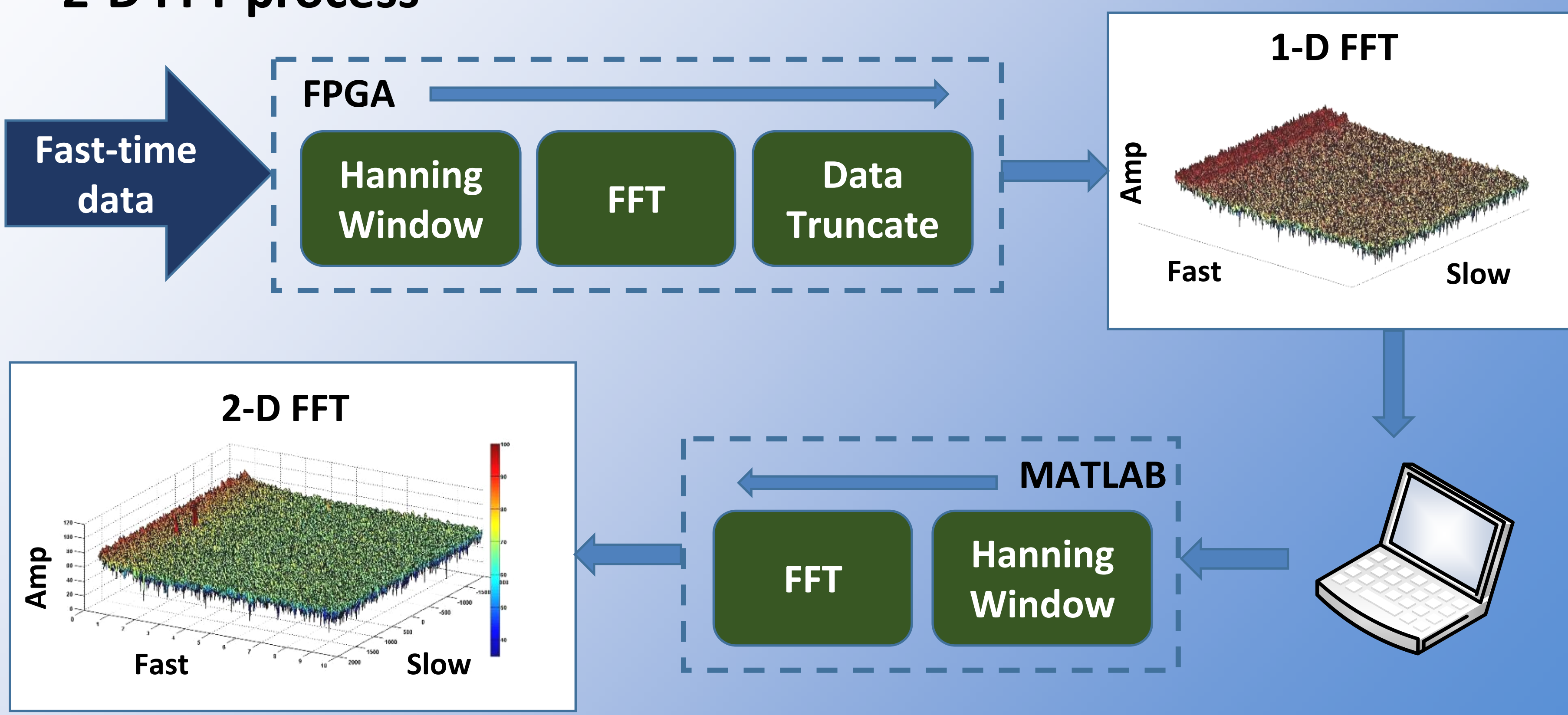
- Performance – lab testing setup (loopback)



Technical approach

- Performance – FPGA processing description

2-D FFT process



Technical approach

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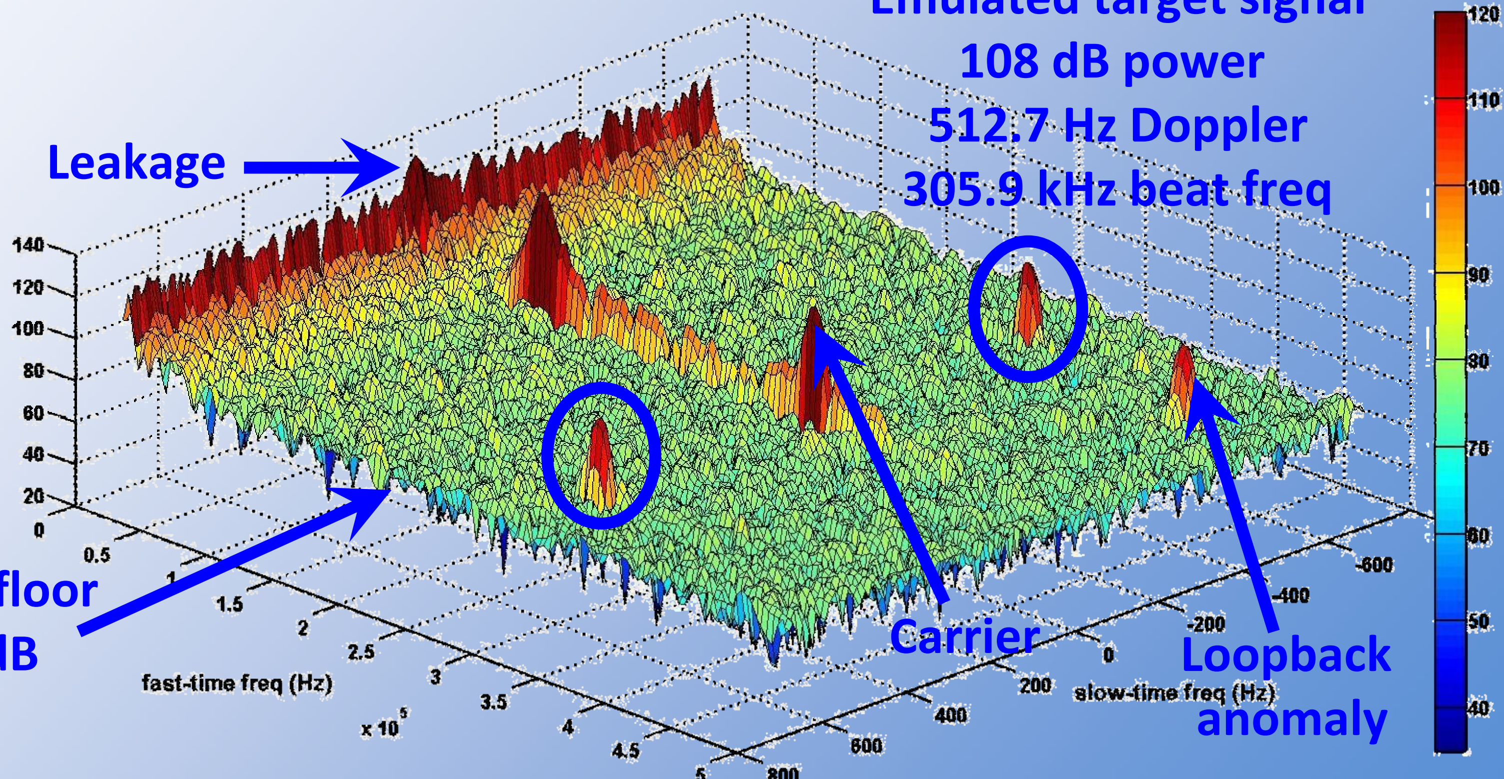
- Performance – FPGA processing example results

3-D graphic output

Loopback setup with leakage using 800-m fiber delay line (584 m range)
Input signal power -112 dBm, 500-Hz double-sideband modulation, output plot truncated in range and Doppler.



Technical approach

- Performance – FPGA processing example results

analysis of output

For the case shown, the following can be determined.

Predicted beat frequency = 305.6 kHz
Measured beat frequency = 305.9 kHz
Emulated target range of 584 m validated

Received signal power = -112 dBm
2-D FFT signal power = 108 dB; Noise power = 85 dB
Signal-to-noise ratio (SNR) = 23 dB

If a 10-dB SNR is required for target detection, then the minimum detectable signal is **-125 dBm**

Theory says **-125 dBm** corresponds to the signal power received from a target with an RCS of **1 m^2** at a range of **430 m**

A target with a larger RCS would be detectable at a greater range.

Technical approach

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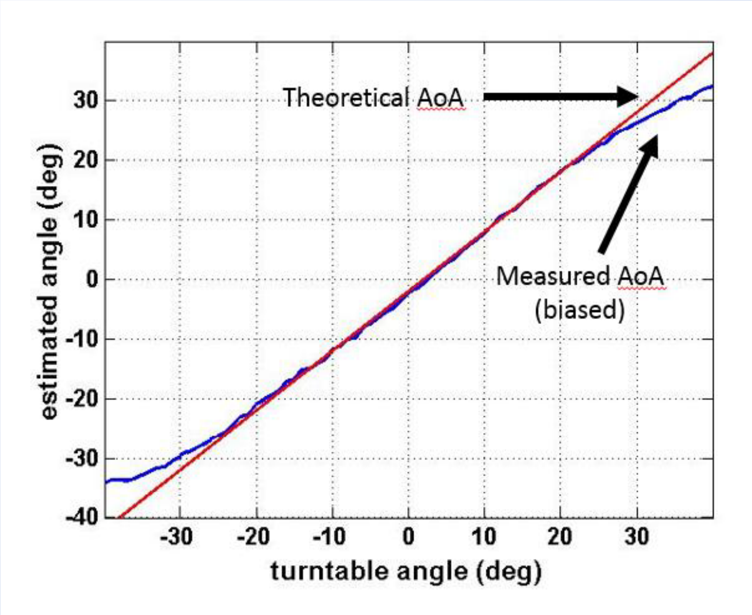
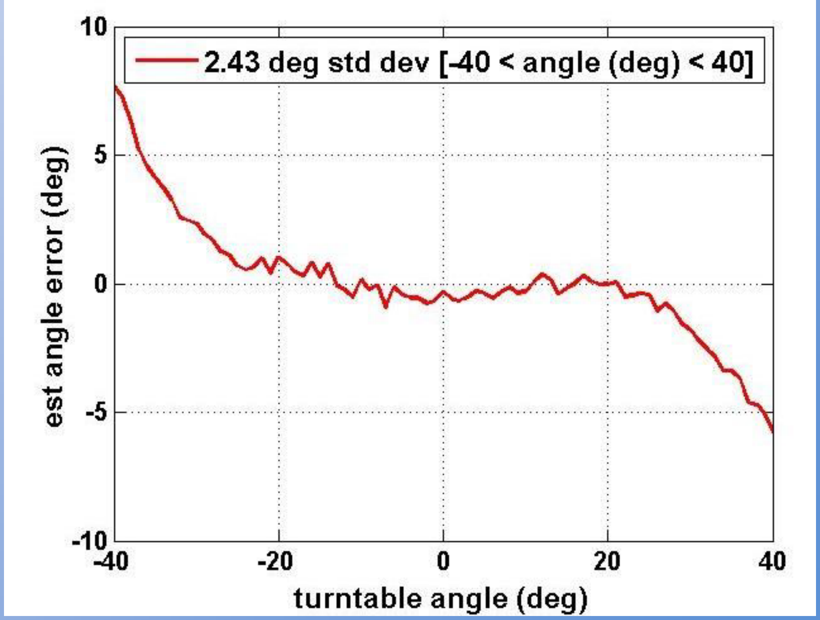
- Performance – antenna array analysis

measured and theory

Inversion of signals from antenna array into angle-of-arrival experimentally verified from data measured in anechoic chamber.

Results confirm inversion algorithm.





Impact of the innovation
if it is eventually implemented

- Sensor represents technology “building block” for assessing the capabilities and limitations of this class of sense-and-avoid radar – a critical step for UAS integration into the National Airspace System.

- With a flight director, this sensor will permit UAS researchers to focus on mission-specific goals (e.g., optimizing flight-control models for the autopilot) when conducting flight tests.

LEARN Phase I results (to date)

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Accomplishments

- Development of ADC board, characterization, integration into radar system.
- Antenna development, characterization, integration into Cessna aircraft.
- FPGA coding for implementing real-time signal conditioning and FFT for flight tests.
  Ongoing work to implement 2-D FFT in FPGA alone (no external computer involved).

LEARN Phase I results (to date)

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Findings

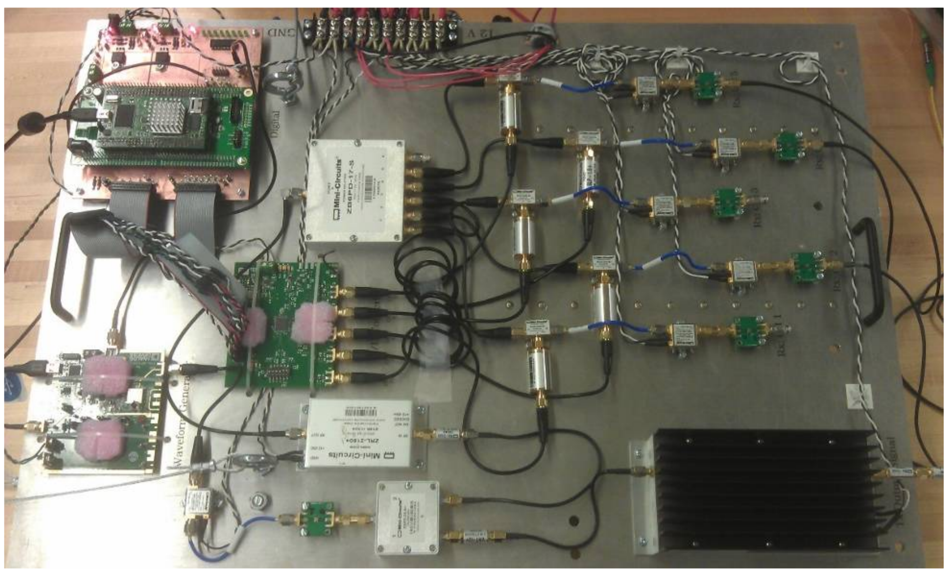
- Lab testing confirms simulations results.
- Techniques for accommodating significant Tx-to-Rx leakage have been successfully demonstrated.
- Execution speed of FPGA code has been shown to be compatible with the real-time processing requirements.
- Investigation shows system can be realized with as few as 3 (maybe 4) receive antennas (vs. 5 in demo system).
- Analysis of angular rate of change shows that only two receive signals need to be processed simultaneously to satisfy unambiguous az. and elev. angles to target (vs. 5 in current demo).

LEARN Phase I results (to date)

Schedule status

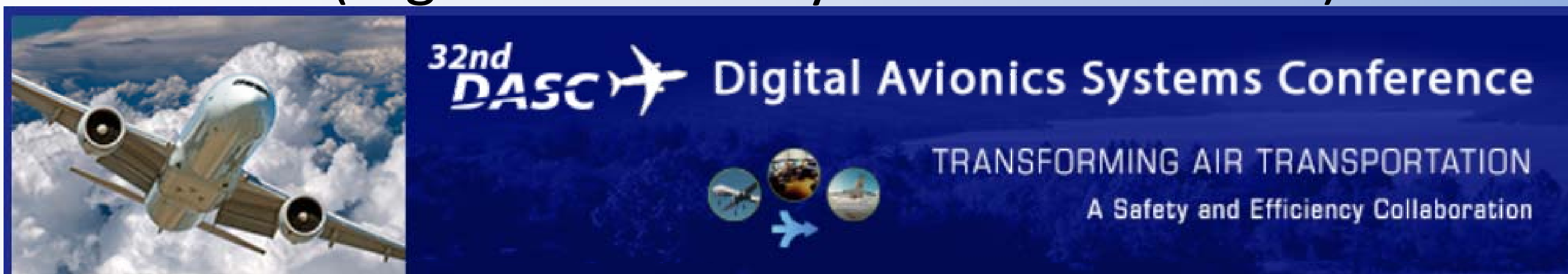
While all benchmarks have been met, the project is behind schedule.

Flight tests were scheduled to begin in Q3 are now beginning is Q4.



Distribution/Dissemination

32nd DASC (Digital Avionics Systems Conference)



Syracuse, NY, October 6-10, 2013

Conference sponsors include:

Our paper (*Multichannel sense-and-avoid radar for small UAVs*) was awarded **best in session** and placed **3rd place overall** in the graduate paper competition

Next steps

- From the challenges overcome and discoveries made in Phase I a clearer vision for Phase II is emerging.
- RF subsystem miniaturization requires a custom printed-circuit assembly.
- Reduction of the Tx-to-Rx leakage on the UAV requires a custom antenna design and analysis.
- Migration to a higher microwave frequency may be required to yield a physically smaller antenna system to meet the UAV's size constraints.
- Close coordination between the radar and the flight director is required henceforth.