SRI CubeSat Imaging Radar for Earth Science (SRI-CIRES)

*Earth Science Technology Forum 2016*

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16 June 2016

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CubeSat Imaging Radar for Earth Science (CIRES)

- Miniaturized SAR for CubeSats
  - Designed for 500 km altitude
  - S-band (2.9 GHz)
  - 25 meter spatial resolution
  - 3.2 m x 1.6 m supporting antenna
  - Sub-centimeter level accuracy

SRI Airborne UHF SAR Heritage
Over 20 years of DT&E and Operational deployments

SRI-CIRES
(<1U CubeSat Volume)

S-Band SAR Subsystem

Circulator Module
Power Amp Module
TX/RX Module
High-speed TX/RX Processor Module

Update with assembled solid model

Approval pending for open publication of photo

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Need for a constellation of InSAR Sensors

- Time-variable geophysical processes require more frequent monitoring than a single InSAR sensor can provide
  - The revisit time of a single platform is restricted by orbital mechanics and spatial coverage requirements (e.g. every 16 days while achieving global coverage)
- Many science applications require sub-cm level deformation measurements, but each individual SAR measurement is corrupted by up to several cm of atmospheric noise.
  - Multiple acquisitions need to be averaged together to reduce atmospheric artifacts

InSAR Constellation Advances Solid-Earth Science by Understanding Geophysical Hazards

Sub-centimeter surface deformation measurements with high temporal resolution will advance our knowledge of critical Earth science questions related to natural hazards and resource mining activities.

The Need for a Low-Cost Constellation of InSAR Satellites

Interferometric synthetic aperture radar (InSAR) is the only tool for measuring spatially dense deformation on a global scale.

Global spatial coverage is needed to capture the infrequent occurrence of natural and human-induced hazards.

Individual SAR satellites cannot provide the rapid revisit times required to characterize geophysical events.

On-orbit Demonstration Enables New Science Missions

A large constellation of InSAR CubeSats with spatial-temporal flexibility is needed to properly characterize time-variable processes and improve predictive geophysical models.
SRI-CIRES: Overview

- Modular self-contained radar instrument generates waveforms, real-time processing and storage of raw I/Q data, and onboard processing of stored data
- Minimizes interfaces to the spacecraft
  - Interfaces required: Command and telemetry, 1PPS, Power, and antenna RF port
- Radar loopback test functions enable ground and satellite checkout of key components without the need for an antenna.

- Non-volatile storage
- High throughput (> 200 MB/s)
- Low power (< 9W peak)
- Low cost COTS parts
SRI-CIRES: Hardware Development

- Concept to Reality: CIRES has key subsystem modules designed, manufactured and currently completing standalone testing

**High Speed Processor Module:**
- Power Regulation, FPGA, Data Storage, Multi-core Processor (not shown, in-work)

**Tx/Rx Module:** Includes: Tx and Rx RF analog chains, calibration loopback circuits, integrated ADC and DAC capability.

**PA Module:** Includes internal power regulation, power driver stages and RF power amplification.
SRI-CIRES: System Verification Loopback Test

• **Goal of Test**
  - Integrate all subsystem modules: PA Module, Tx/Rx Module, High Speed Processor Module (development boards used for the latter)
  - Transmit linear FM chirp at 600W RF peak power, attenuate, and loopback into the receive chain for data storage and read back.
  - Verify 25m range resolution goal through match filter processing

• **Results**
  - Data plotted below shows one 20 microsecond pulse from a sequence of pulses
  - Range-compressed pulse matches expected ideal pulse response
  - Recorded data at 150MB/sec
SRI-CIRES: PA Module Stand-Alone Testing (Ambient)

- Thermal Model Analysis Boundary Conditions for ambient test
  - New passive PA Module enclosure design and mounted to heat sink.
  - Duration of Transmit (Goal: 9 mins or 10% of an orbit)
  - Heat Flux
    \[ Q_{\text{net}} = Q_{\text{IN}} - Q_{\text{RFout}} = (11.5\text{A})(15\text{V}) - 60\text{W} = 114\text{ W} \]
  - Ambient Temperature = 23 degC
SRI-CIRES: PA Module Stand-Alone Testing (Ambient)

**Experiment Model**
- \( T_{C1_{EXP}} \)\_max = 37.8 °C
- \( T_{C2_{EXP}} \)\_max = 39.9 °C
- \( T_{C3_{EXP}} \)\_max = 40.7 °C
- \( T_{C4_{EXP}} \)\_max = 37.8 °C

**Theoretical Model**
- \( T_{C1_{THY}} \)\_max = 39.9 °C (% Diff: 5.6%)
- \( T_{C2_{THY}} \)\_max = 40.0 °C (% Diff: 0.25 %)
- \( T_{C3_{THY}} \)\_max = 39.6 °C (% Diff: 2.7 %)
- \( T_{C4_{THY}} \)\_max = 37.8 °C (% Diff: 0 %)
SRI-CIRES: PA Module Stand-Alone Testing (Ambient)

Ambient Experiment Data - 9min Continuous Radar Pulses
SRI-CIRES: PA Module Stand-Alone Testing (Vacuum)

- Thermal Model Analysis Boundary Conditions for vacuum test
  - Vacuum: $10^{-5}$ Torr
  - Passive PA Module enclosure design and mounted to heat sink.
  - Duration of Transmit (Goal: 9 mins or 10% of an orbit)
  - Heat Flux: $Q_{net} = Q_{IN} - Q_{RFout} = (11.5A)(15V) - 60W = 114\text{ W}$
  - Ambient Temperature = 20 degC
SRI-CIRES: PA Module Stand-Alone Testing (Vacuum)

Thermal Model Analysis in Vacuum

- **Hot Case** ($T_{on} = 45^\circ C$)
  - $T_j = 117.6^\circ C$ (PA Max Junction Temp: 190°C)
  - $T_{enclosure} = \sim 60^\circ C$

- **Cold Case** ($T_{on} = -30^\circ C$)
  - $T_j = 51.1^\circ C$
  - $T_{enclosure} = \sim -5^\circ C$
SRI-CubeSat Imaging Radar for Earth Science (SRI-CIRES)
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Objective

- Develop S-Band radar electronics subsystems capable of interferometric synthetic aperture radar (InSAR) operations for the CubeSat platform
  - Volume less than 1 U (10x10x10 cm) and <750g
  - Low phase noise (e.g., accurate, stable reference clock)
- Satisfy the performance requirements for Earth Science applications that benefit from rapid-repeat InSAR, e.g. natural hazard and resource monitoring
  - High-quality imaging (SNR >13dB)
  - Sub-cm level InSAR accuracy
  - Spatial resolution better than 30 m

Approach

- Leverage SRI expertise in UHF SAR and InSAR development and miniaturizing payloads for the CubeSat platform
- Leverage SRI IRAD investments in a CubeSat high-speed I/Q data processor and storage (120 MBps)
- Validate prototype SAR subsystem performance in the laboratory and in relevant environments, e.g., vibration, thermal, and vacuum

Co-Is/Partners: Simon Lee, John Buonocore, Roman Novoselov, Troy Stevens, SRI Int’l; Howard Zebker, Stanford Univ.

Key Milestones (assumes mid-Jan, 2015 start)

- Develop performance requirements for InSAR science missions 03/15
- Complete radar system design 05/15
- Define board-to-board interface requirements 06/15
- Complete breadboard subassembly testing 10/15
- Complete fabrication of prototype modules 05/16
- Integrate and test prototype assembly 06/16
- Demonstrate end-to-end performance in relevant environment 08/16

TRI in = 2
Thank you!

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