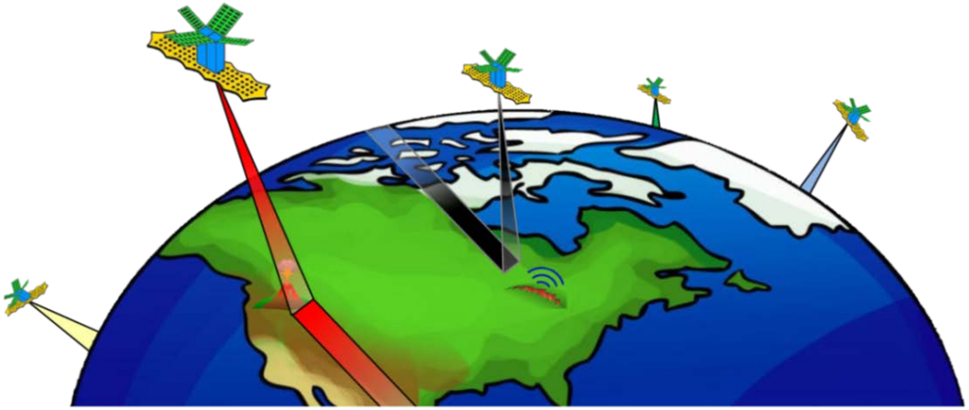
SRI CubeSat Imaging Radar for Earth Science (SRI-CIRES)

Earth Science Technology Forum 2016



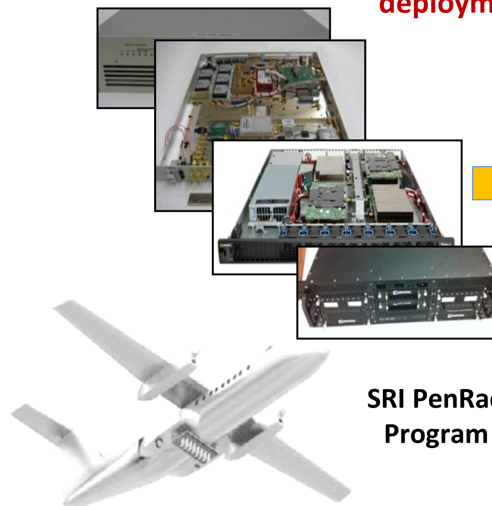
Lauren Wye & Simon Lee
SRI International
16 June 2016

Collaborators: John Buonocore, Michael Huff, Troy Stevens, Roman Novosolev, David Watt, Steven Chen, Joe Wilhelm, Patrick Rennich, Prof. Howard Zebker

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

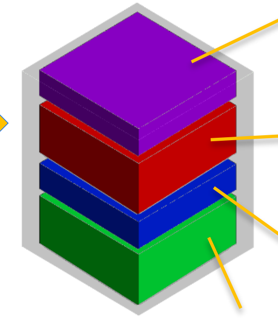
SRI Airborne UHF SAR Heritage
Over 20 years of DT&E and Operational deployments

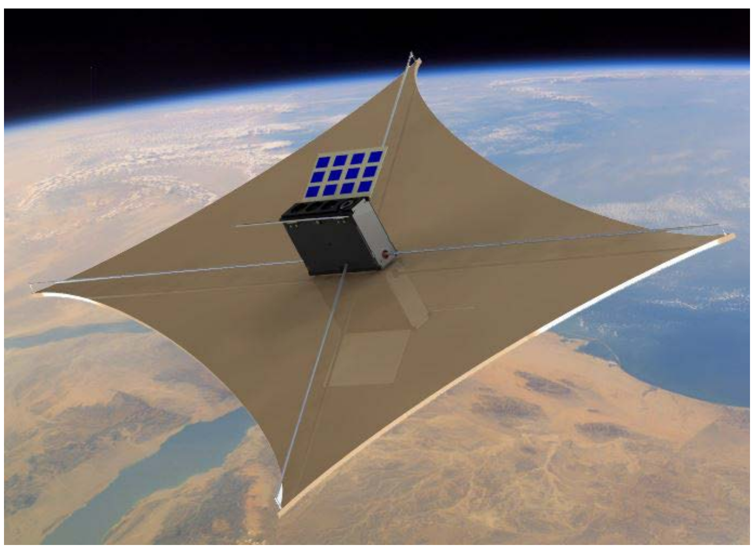


SRI PenRad Program

S-Band SAR Subsystem

SRI-CIRES
(<1U CubeSat Volume)





Update with assembled solid model

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

CIRES Address NASA Science Goal: Understanding Extreme Events including Earthquakes and Volcanic Eruptions

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.

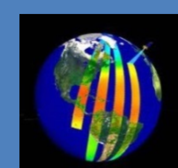
The Need for a Low-Cost Constellation of InSAR Satellites

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.

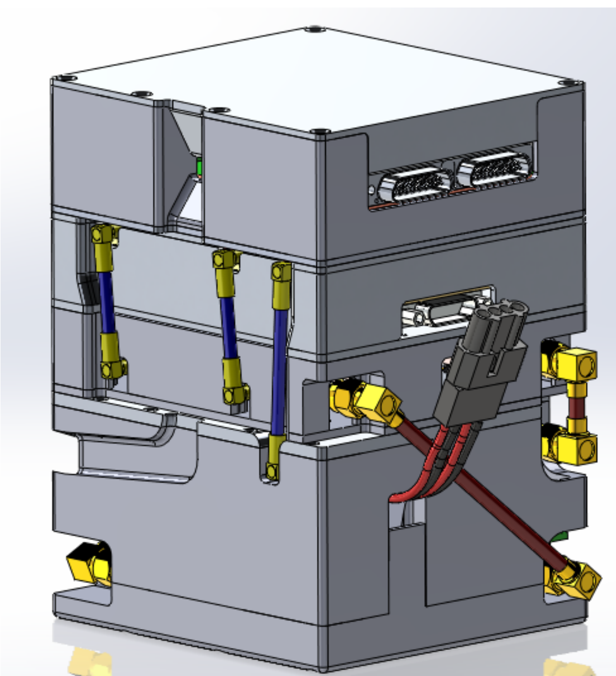
On-orbit Demonstration Enables New Science Missions



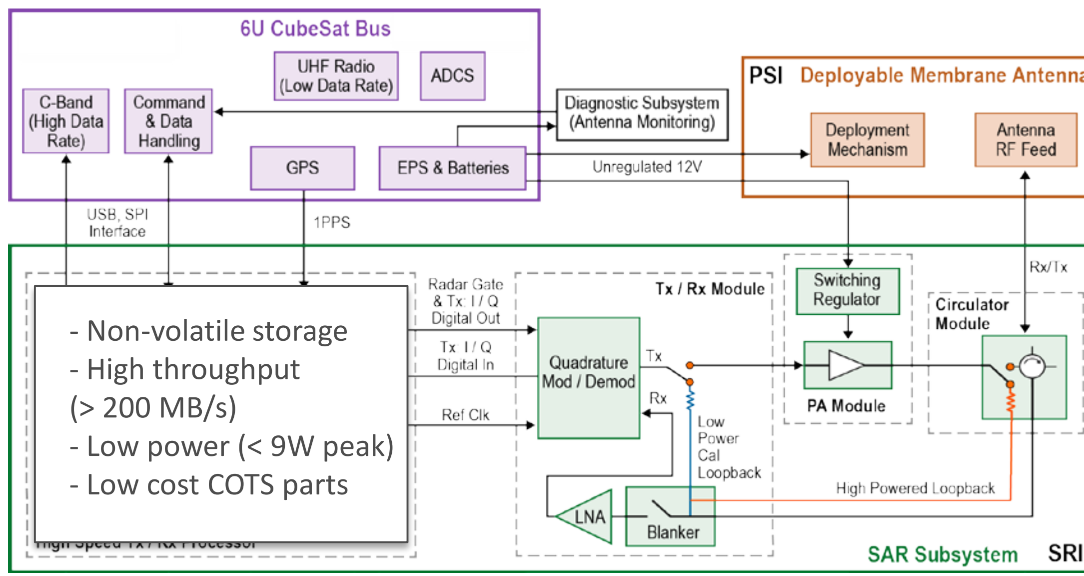
A large constellation of InSAR CubeSats with spatial-temporal flexibility is needed to properly characterize time-variable processes and improve predictive geophysical models.

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.

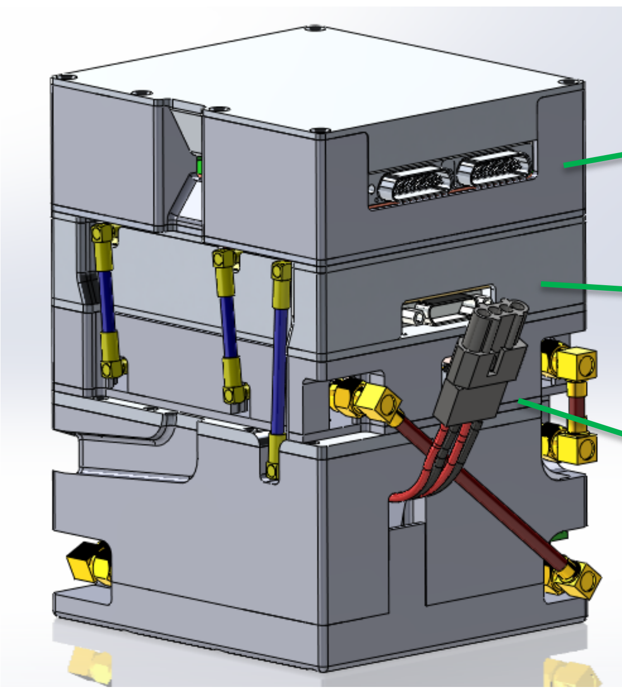


SRI-CIRES Solid Model ~1.5U Radar Payload



SRI-CIRES: Hardware Development

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



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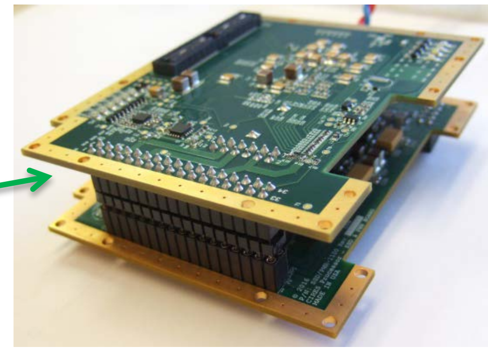
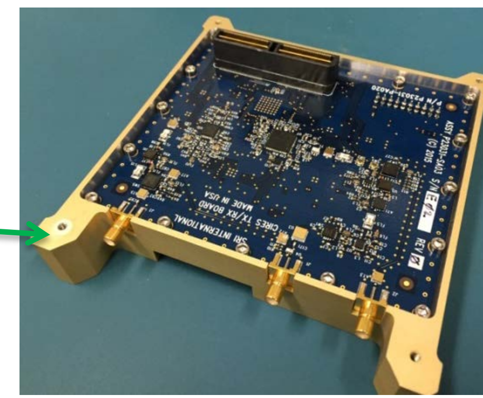
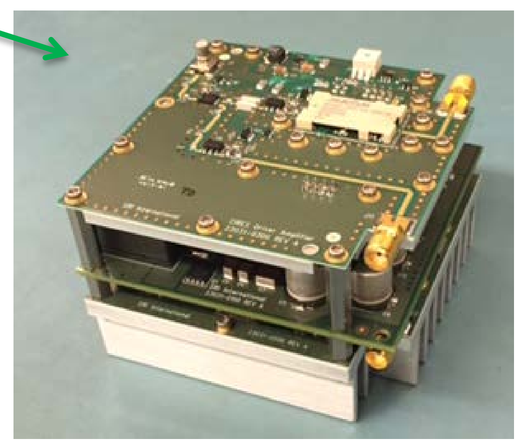


High Speed Processor Module: Power Regulation, FPGA, Data Storage, Multi-core Processor (not shown, in-work)



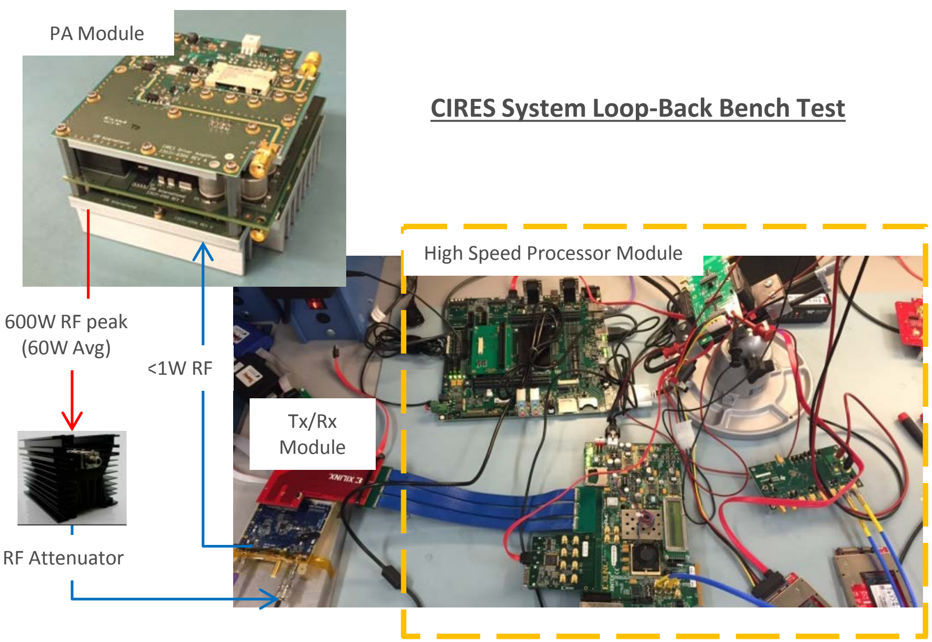
Tx/Rx Module: Includes: Tx and Rx RF analog chains, calibration loopback circuits, integrated ADC and DAC capability.

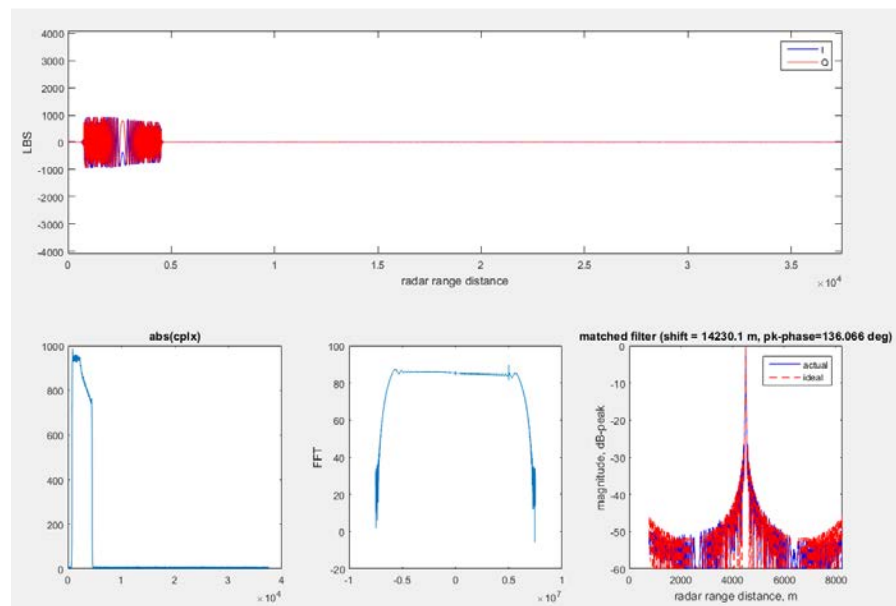


PA Module: Includes internal power regulation, power driver stages and RF power amplification.

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



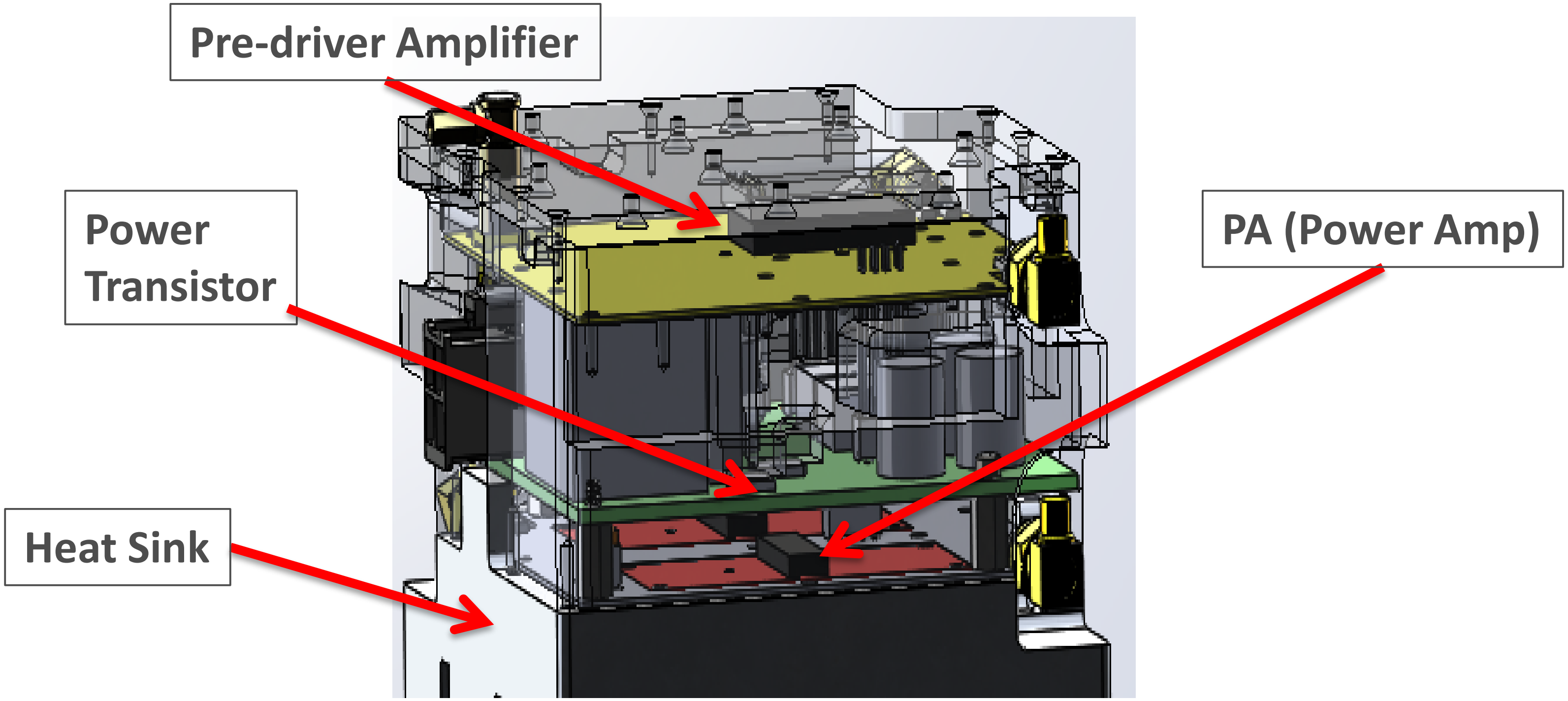


SRI-CIRES: PA Module Stand-Alone Testing (Ambient)

- 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

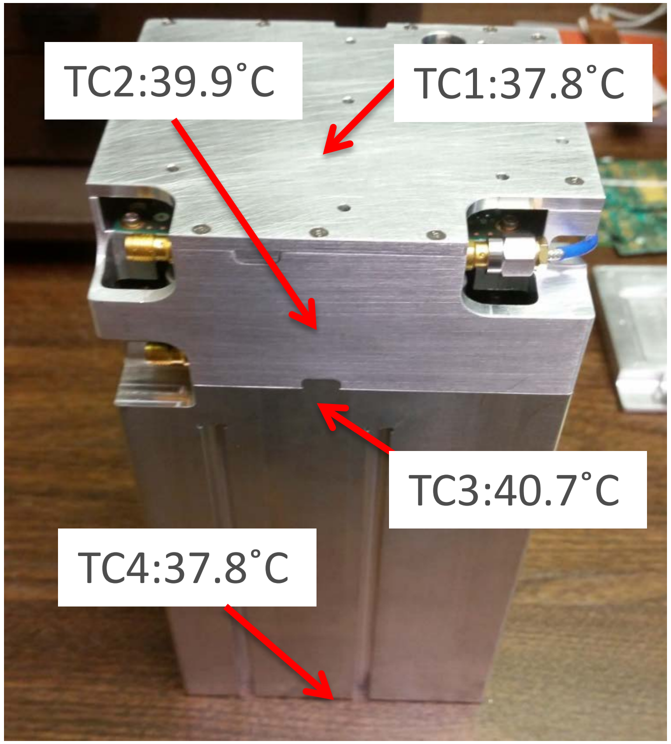
    $Q_{net} = Q_{IN} - Q_{RFout} = (11.5A)(15V) - 60W = \underline{\mathbf{114\ W}}$

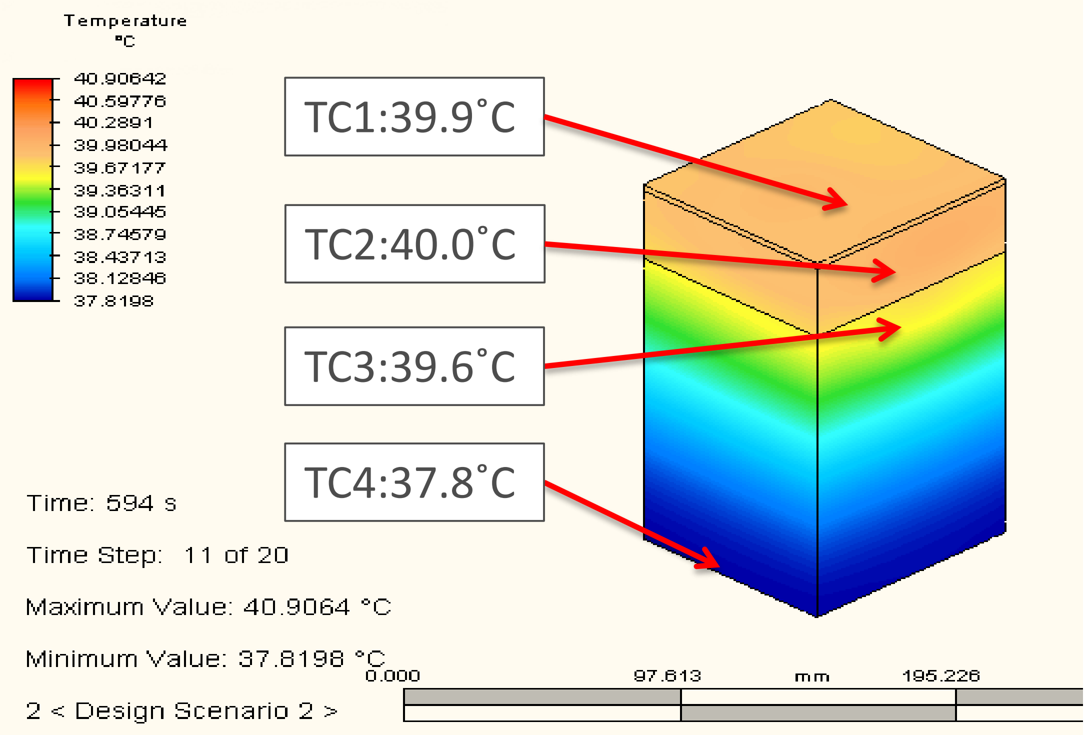
  - Ambient Temperature = 23 degC



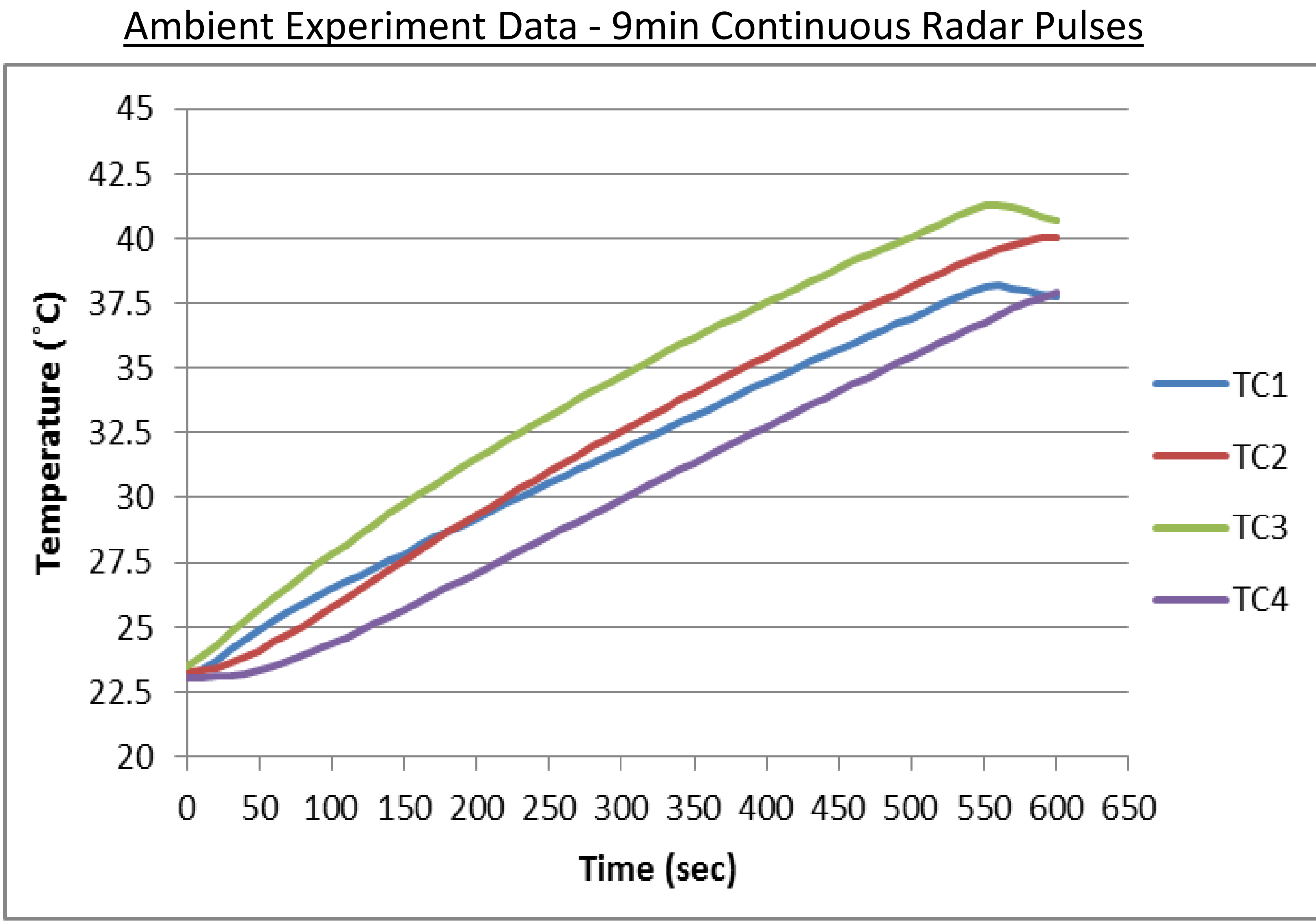
SRI-CIRES: PA Module Stand-Alone Testing (Ambient)

- **Experiment Model**
  - **$TC1_{EXP-max}$ = 37.8 ˚C**
  - **$TC2_{EXP-max}$ = 39.9 ˚C**
  - **$TC3_{EXP-max}$ = 40.7 ˚C**
  - **$TC4_{EXP-max}$ = 37.8 ˚C**
- **Theoretical Model**
  - **$TC1_{THY-max}$ = 39.9˚C (% Diff: 5. 6%)**
  - **$TC2_{THY-max}$ = 40.0˚C (% Diff: 0.25 %)**
  - **$TC3_{THY-max}$ = 39.6˚C (% Diff: 2.7 %)**
  - **$TC4_{THY-max}$ = 37.8˚C (% Diff: 0 %)**



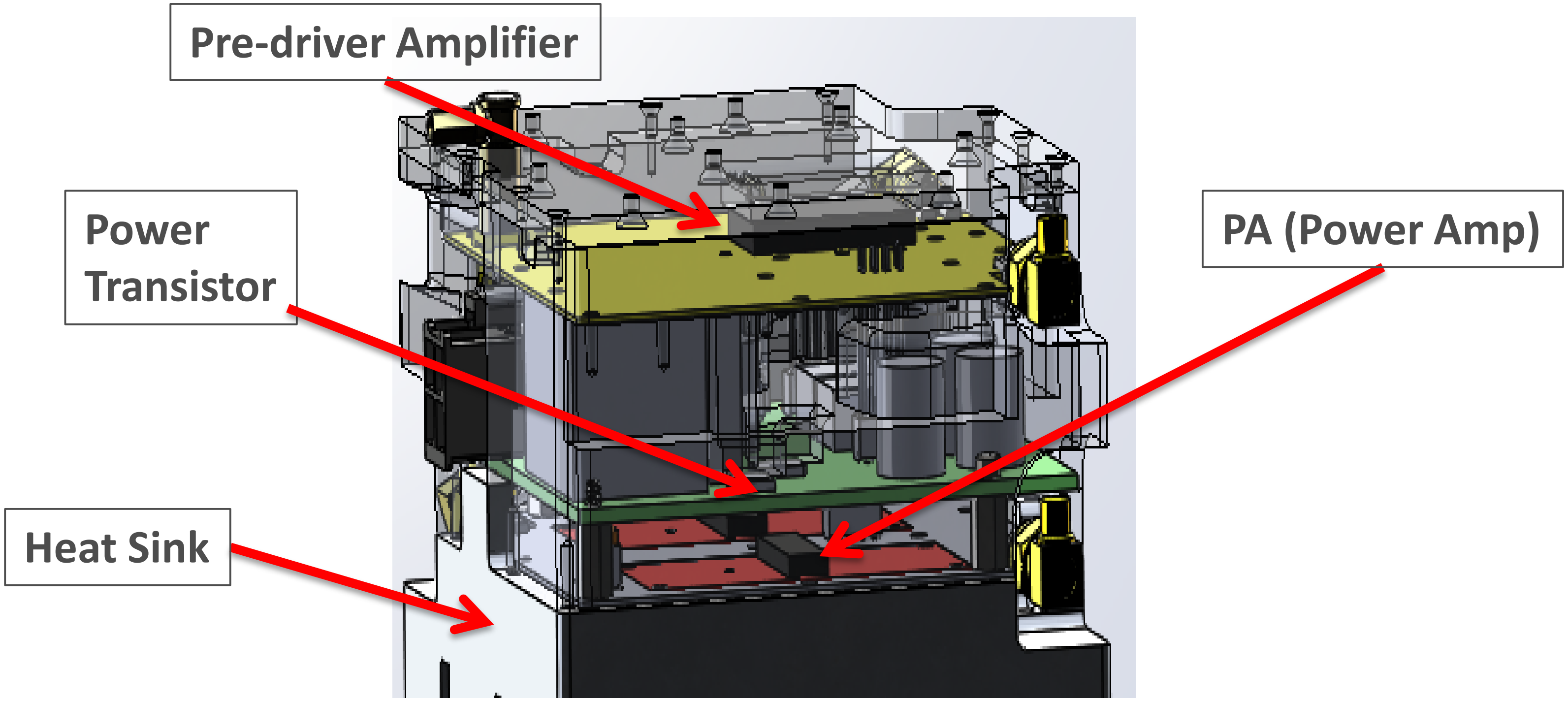


SRI-CIRES: PA Module Stand-Alone Testing (Ambient)



SRI-CIRES: PA Module Stand-Alone Testing (Vacuum)

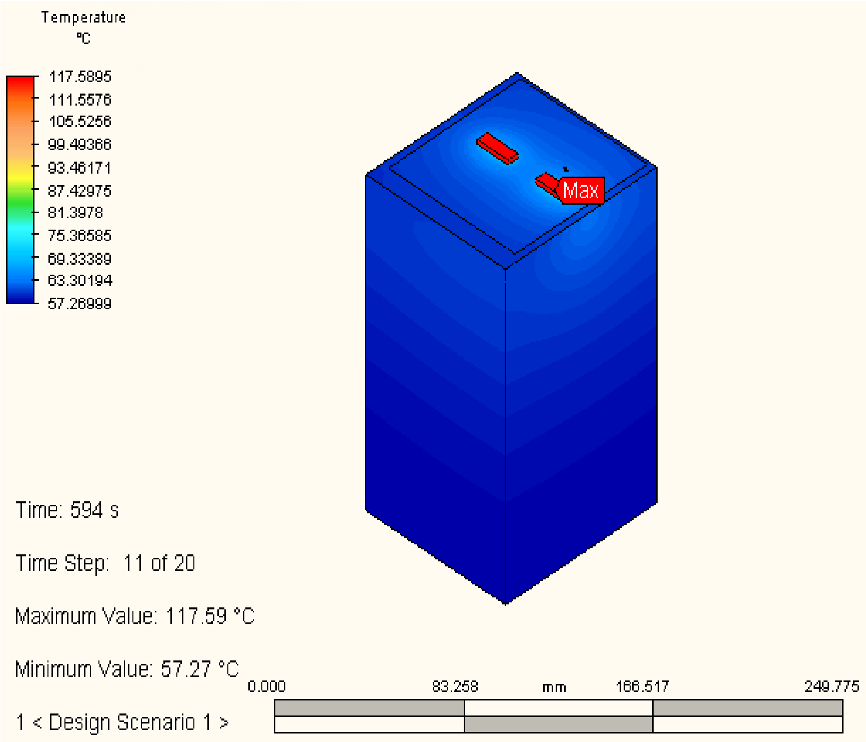
- Thermal Model Analysis Boundary Conditions for vacuum test
  - Vacuum: 10^-5 Torr
  - Passive PA Module enclosure design and mounted to heat sink.
  - Duration of Transmit (Goal: 9 mins or 10% of an orbit)
  - Heat Flux: $Q_{net} = Q_{IN} – Q_{RFout}$ = (11.5A)(15V) – 60W = **114 W**
  - Ambient Temperature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

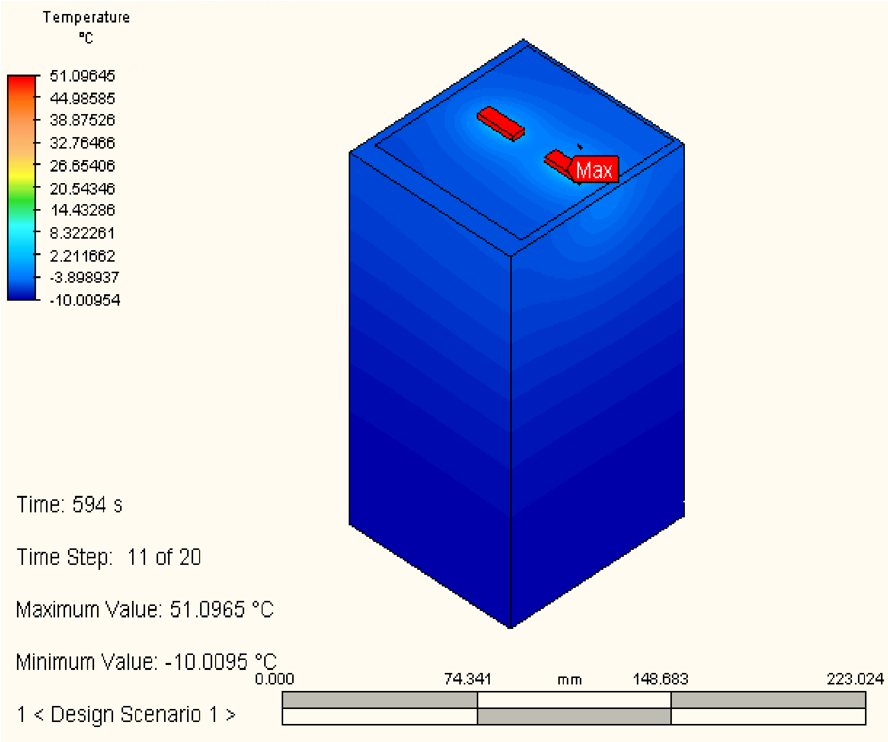


SRI-CIRES: PA Module Stand-Alone Testing (Vacuum)

Thermal Model Analysis in Vacuum

- **Hot Case (T_{on} = 45˚C)**
  - T_j = 117.6˚C (PA Max Junction Temp: 190C)
  - $T_{enclosure}$ = ~60˚C
- **Cold Case (T_{on} = -30˚C)**
  - T_j = 51.1˚C
  - $T_{enclosure}$ = ~-5˚C



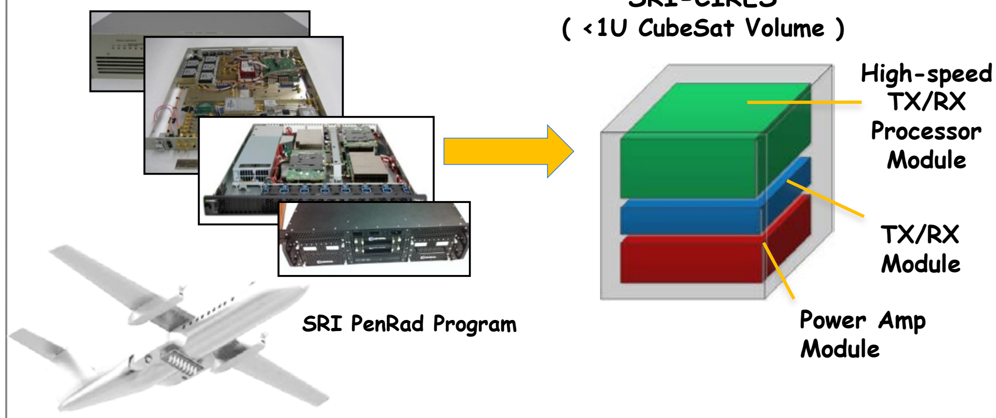


SRI-CubeSat Imaging Radar for Earth Science (SRI-CIRES)

PI: Lauren Wye, SRI International

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

$TRL_{in} = 2$

Thank you!

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