Jet Propulsion Laboratory
California Institute of Technology

NASA L-SAR Instrument for the NISAR (NASA-ISRO) Synthetic Aperture Radar Mission

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What is NISAR

NASA-ISRO Synthetic Aperture SAR

Joint* US-India 3-year Science Mission

- Solid Earth
  - 12-day repeat over solid earth
  - 0.1 to 50 km swath
  - 3.5mm height accuracy, 100m res
  - Velocities < 1mm/yr
- Land Ice
  - 6-day repeat over land ice
  - 100mm displacement accuracy
- Sea Ice
  - Monitor up to 100m/day velocities
  - 5km grids
- Biomass
  - Measure woody biomass and disturbance at hectare scales
  - Accuracy of 20 Mg/Ha

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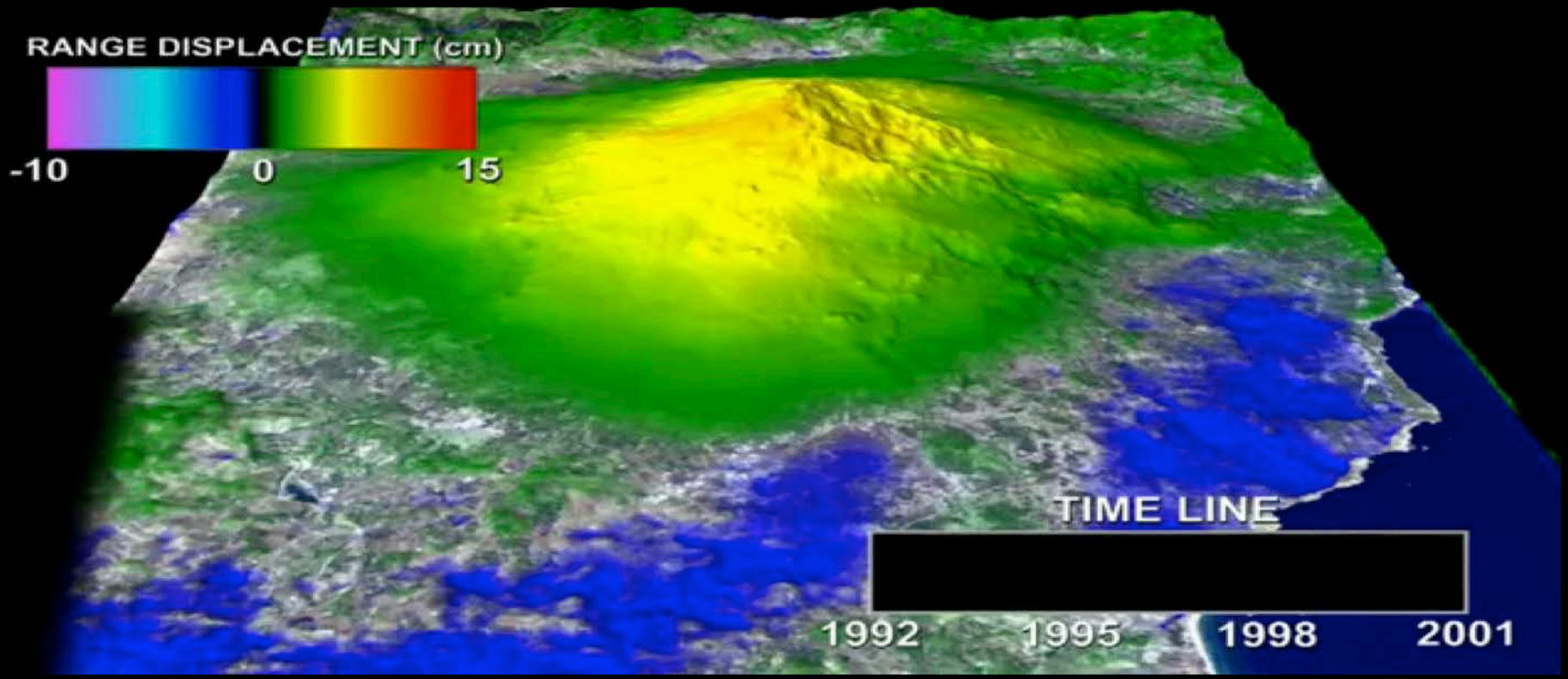
SoCal Surface Deformation Due to Groundwater (InSAR)

California “Great Shakeout”

Modeling a magnitude 7.3 earthquake in California

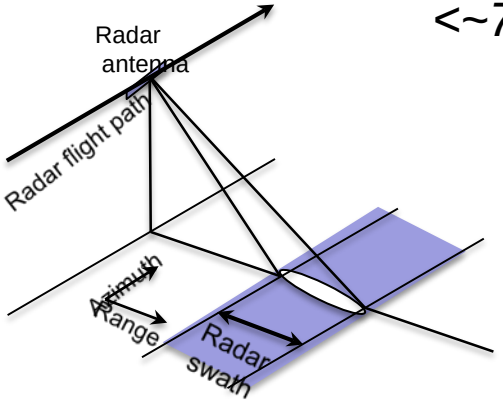
- August 2001, FEMA predicted the three top disaster risks to be 1) A major terror attack, 2) A devastating hurricane in and unprepared region 3) >7.0 earthquake in major US city
- USGS predicts >80% chance of ?7.0 earthquake occurring in Southern California within the decade
- Since 2001, 8700 buildings in Los Angeles have been retrofitted or replaced, but 7500 school buildings, 17/19 Public Safety Command Centers, and 900 hospitals remain unreinforced
- Previous, similarly sized earthquakes have resulted in ruptures ~500km long, with >10 meter displacements
- Duration of initial major shock ~4 minutes
- Damage estimates exceed $150B
- Californians are asked to have 3-5 days water, medicine, but estimates predict basic services would be absent for weeks to months


RANGE DISPLACEMENT (cm)
-10
0
15
TIME LINE
1992
1995
1998
2001

Why SweepSAR?

- Repeat Period requirement for Deformation science drives the Radar Swath
  - For a sub two week Repeat Period, a Swath Width greater than 200km is required
- Sensitivity requirement for Biomass (cross-pol) measurement drives Antenna Size and Radar Power
- Accuracy requirements for Deformation and Biomass drive Electronics & Mechanical Stability and Calibration
- SweepSAR was adopted to achieve much wider swath than conventional SAR strip-mapping, without the performance sacrifices associated with the traditional ScanSAR technique

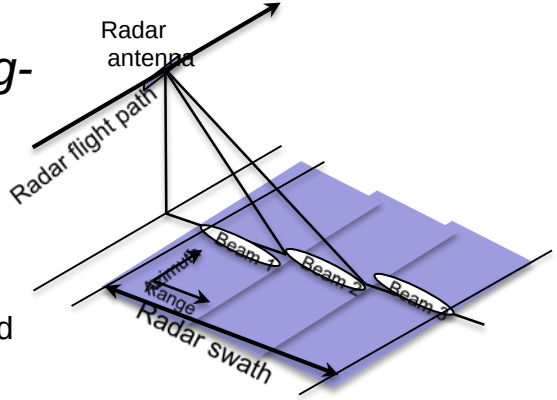
Conventional StripMap: <~70km Swath



Resulting ~40 day repeat does *NOT* meet Proposed Deformation and Ice Science Requirements

Conventional ScanSAR: non-uniform along-track sampling

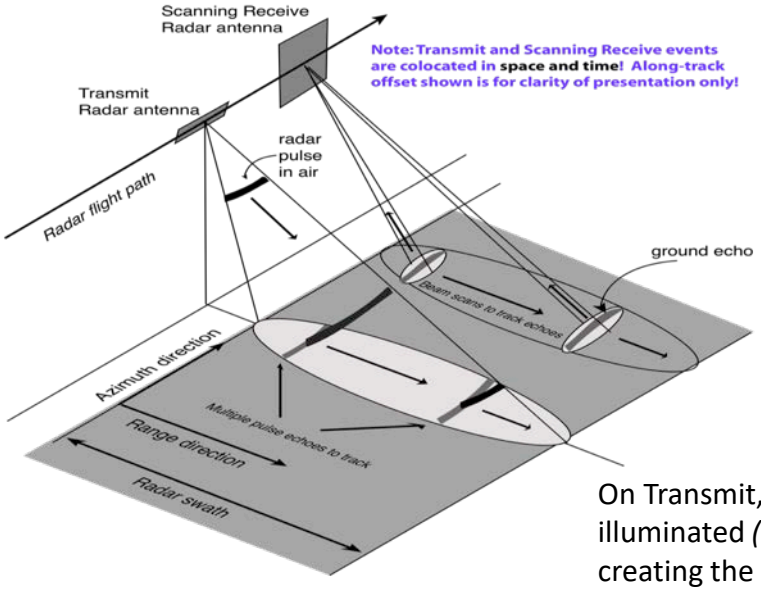
Resulting degradation in effective azimuth looks does *NOT* meet Proposed Ecosystem Science Requirements



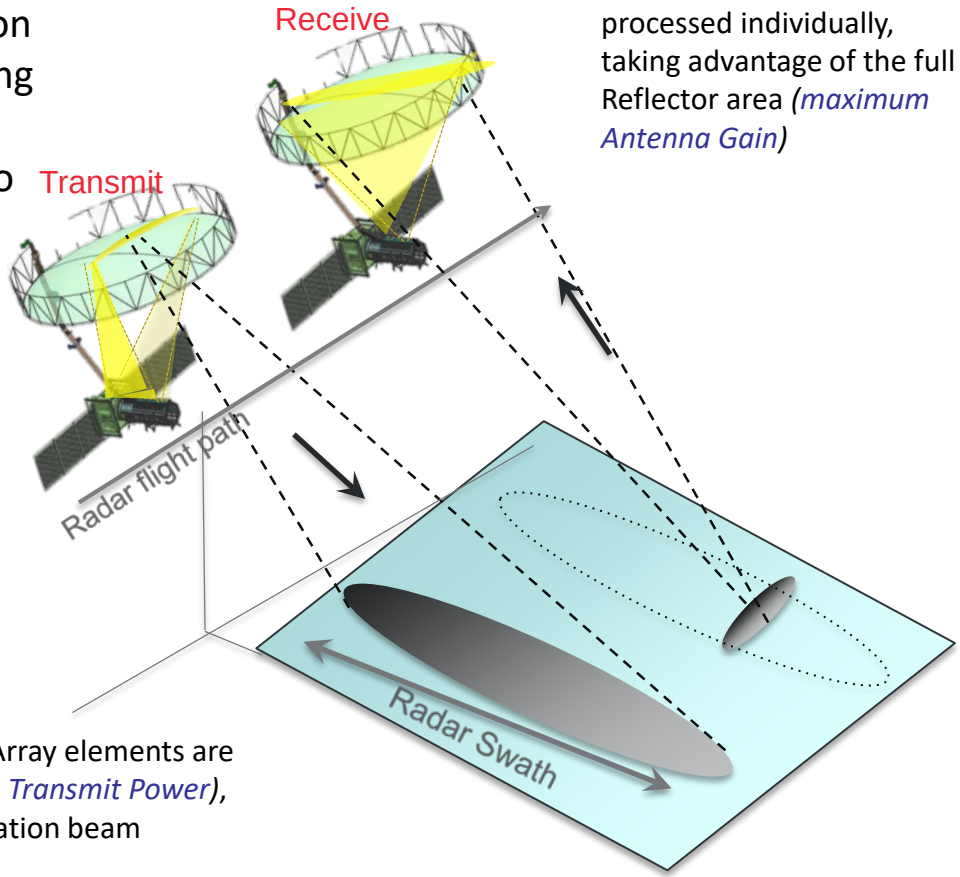
SweepSAR Technique

What is SweepSAR?

- Transmits a pulse over wide beam in elevation
- Receives the echo over narrow beam, tracking echo with scanning receive beam
- Uses multiple *simultaneous* receive beams to track multiple echoes



On Receive, the Feed Array element echo signals are processed individually, taking advantage of the full Reflector area *(maximum Antenna Gain)*



On Transmit, all Feed Array elements are illuminated *(maximum Transmit Power)*, creating the wide elevation beam

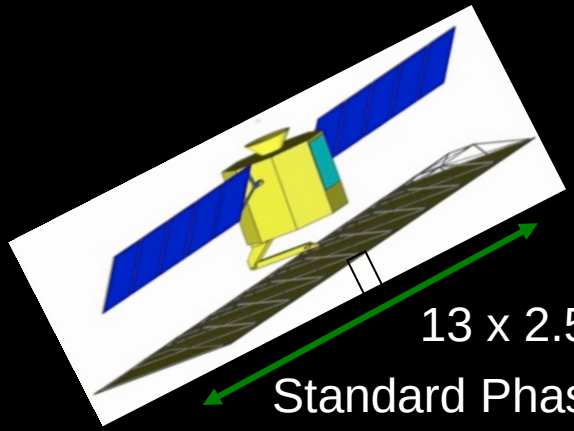
L-SAR Technology Development

- L-SAR instrument evolved most recently from the radar portion of DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice)

High Power Density Phased Arrays

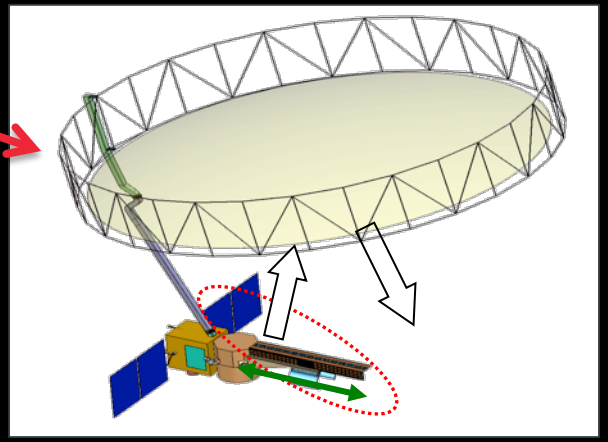
The SweepSAR reflector architecture is expected to be more cost effective than a traditional phased array, but the RF and DC power densities become much higher. Development focused on improving reliability for high power densities

- Increase RF power density
- Improve component stability
- Enable new instrument architecture



Standard Phased Array

Assuming 3kW RF Peak Transmit



Phased Array Feed

- Lower RF Power Density (92 W/m^2)
- Larger Radiator Area (32.5 m^2)
- Higher Thermal Inertia

- Higher RF Power Density (1500 W/m^2)
- Smaller Radiator Area (2 m^2)
- Lower Thermal Inertia

Key Hardware Technologies Studied

Decreasing DC power, thermal variability and thermal mismatch

- Phase Change Material (thermal capacitor)
  - Phase change material, when properly designed, was shown to reduce thermal excursions by up to 90%
  - Final designs for what became L-SAR no longer required the material and the complexity was high
- Constrained Thermal Expansion Material for RF Chassis
  - Several varieties of Silicon Aluminum Alloy were tested
  - Direct attachment of Gallium Arsenide die to these alloys survived over 1000 NASA thermal cycles, with no degradation (cracking, lifting)
  - Final designs avoided bare-die devices and did not require exotic materials
- Gallium Nitride (GaN) RF transistors
  - Now baseline for L-SAR-details to follow

GaN High Power Amplifier for L-SAR

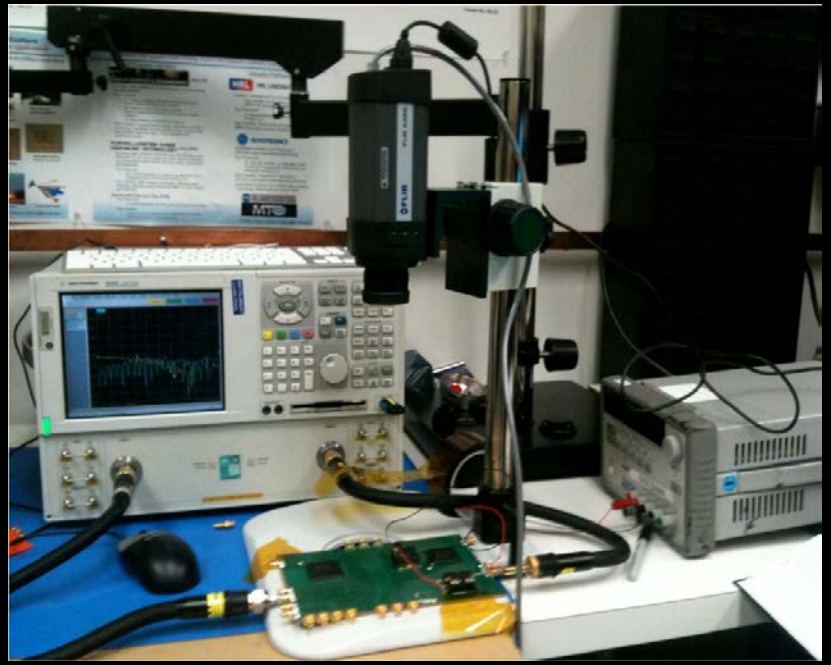
Increased RF output, with decreases in DC power and heat

- Exhaustive studies of GaN-based high-power amplifiers showed that DESDynI could decrease it's DC power by almost half of a kilowatt by moving from then-state-of-art Bipolar devices to GaN
- DC power savings are matched by a decrease in waste heat
- JPL tested devices from multiple vendors for TID (total dose) and SEE (Single Event Effects)
  - All devices tested showed no ill-effects from radiation, up to our required levels
  - L-SAR now has 24 GaN High Power Amplifiers

RF Thermal Packaging

GaN HPA designs were also tested thermally, for reliability and instrument performance stability

- Image on right is FLIR thermal camera test station
- A similar test was performed in thermal chamber
- Design team proved the devices would not exceed NASA standards for device temperature and that the transmitters would be very thermally stable



Real-time Digital Calibration Development

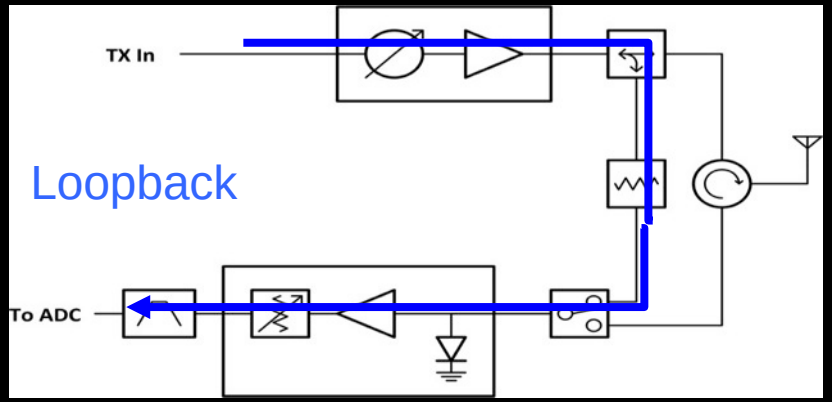
Real-time digital calibration

(aka digi-cal)

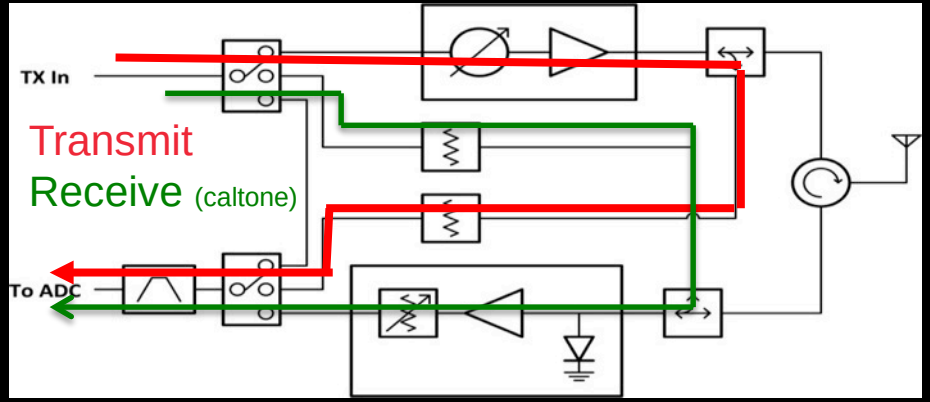
- The SweepSAR technique is very powerful, and enables large swath imaging, but introduces new challenges
- 24 independent transmitters and receivers must be made to work as one, with little help from the ground
  - Data rates preclude sending all 24 channels to the ground for processing, so significant processing must take place on-board
  - Once channels are combined, errors in individual channels cannot fully be corrected, so this must take place on-board
  - Data volumes dictate that much of this processing must take place in real-time
- By leveraging the 24 independently digitized channels, we are able to calibrate both transmit and receive on-board, prior to beamforming

SweepSAR calibration concept

Traditional Loopback Calibration

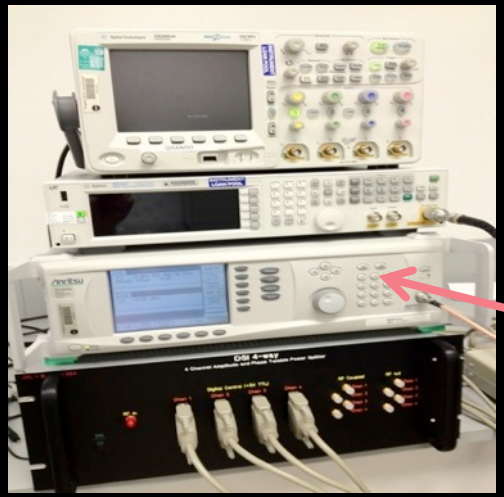


SweepSAR Digital Calibration

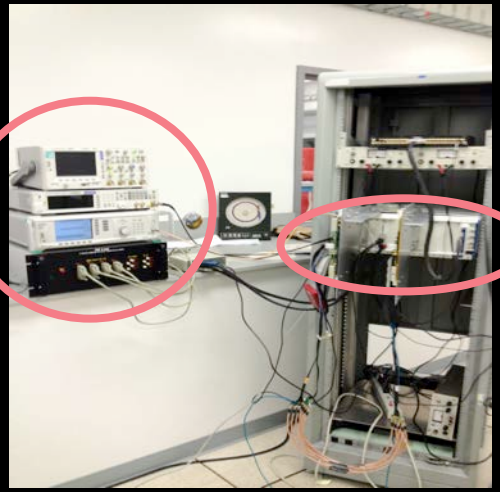


- **Relaxes the isolation requirement between TX and RX**
- **Calibration can be done during actual receive events**
- **Differentiates between TX and RX changes (important for SweepSAR)**
- **Compensates for all changes not just temperature**

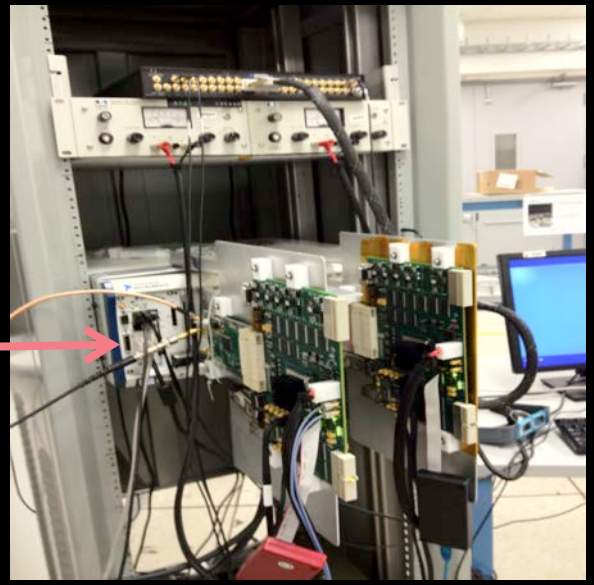
Calibration Testbed (breadboarding)



Multi-channel excitation: Single channel of CW or chirp, through an computer controlled 4-way splitter with independent control of phase and amplitude.

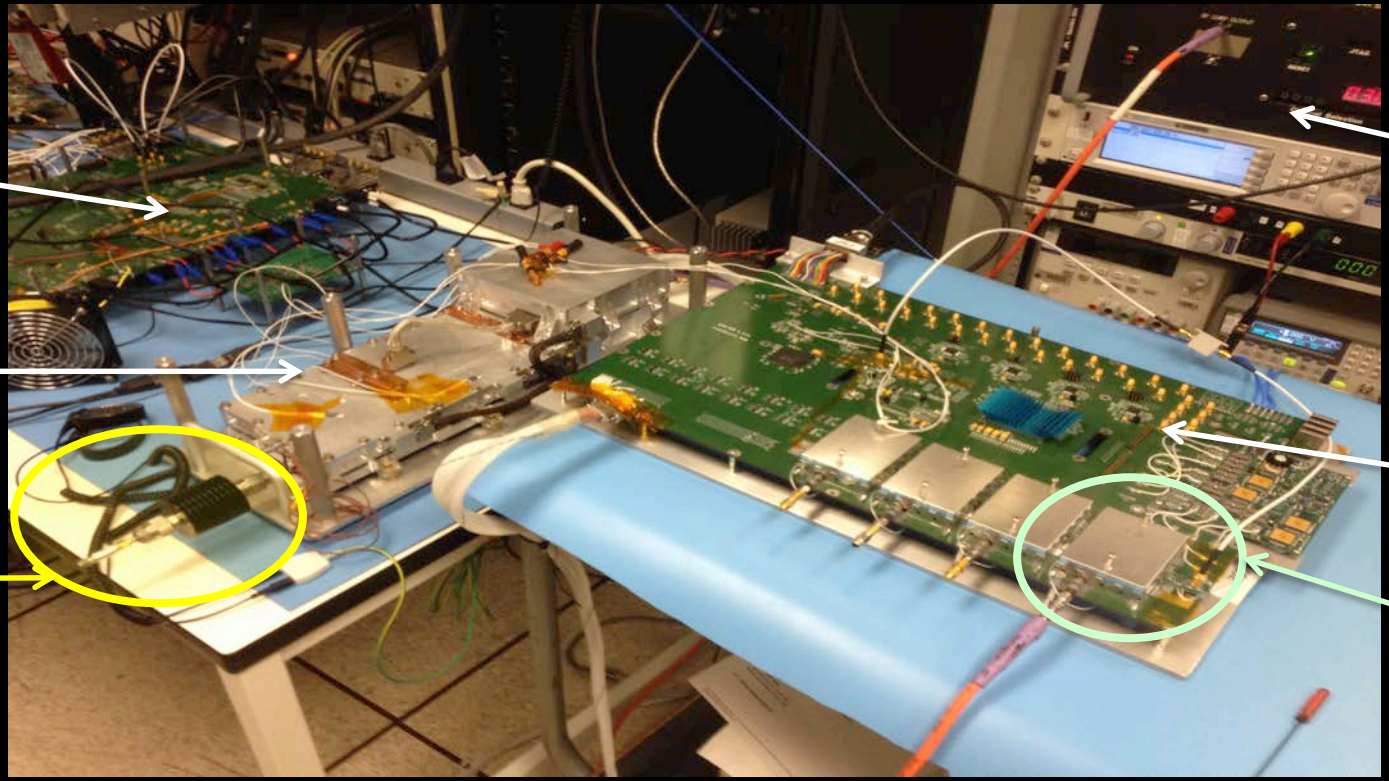


Digital Calibration Testbed



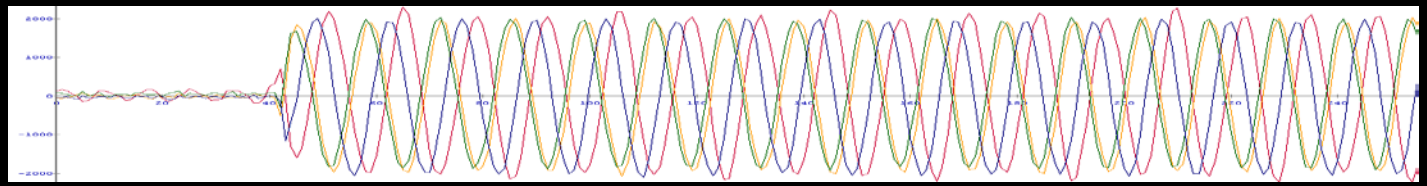
iFSP (First Stage Processor breadboard in an iBoard4); iSSP (Second Stage Processor breadboard in iBoard4); and a National Instruments cPCI chassis acting as RIC (Radar Instrument Controller)

SweepSAR/Digi-Cal “First Light”

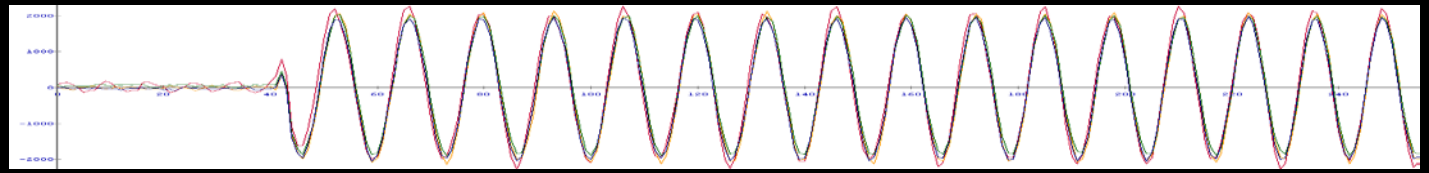


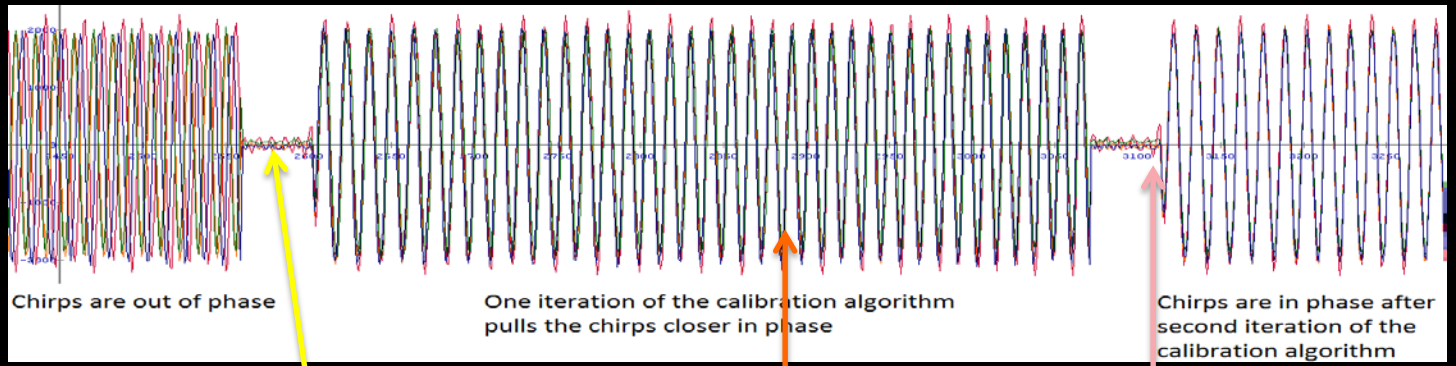
Transmit Calibration Result Example

4 channel pre-calibration



4 channel calibrated





Calibration enabled here

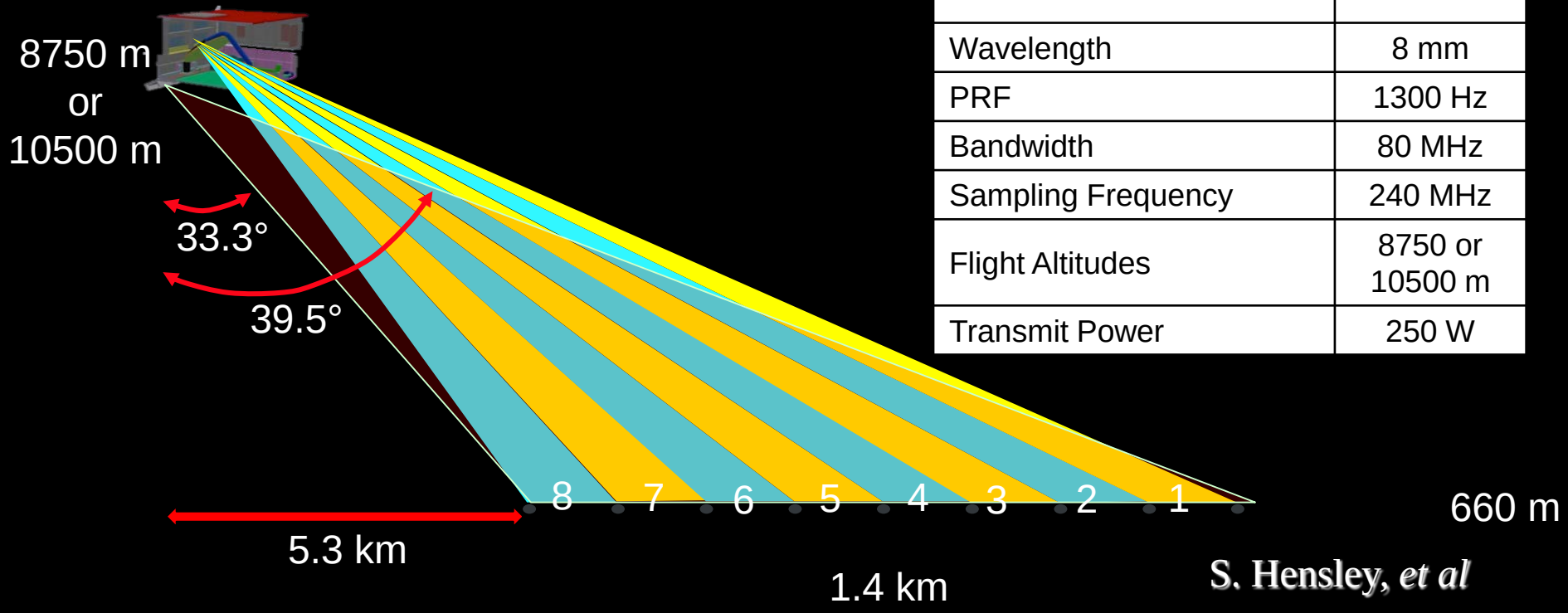
Calibration iterates

Calibration Complete

Airborne Demostration

Airborne Demo

- Data was collected on eight beams, mapping a swath extending from 33.3°-39.5° that gives a swath width of 1.4 km
- Calibration and imaging was done on the ground



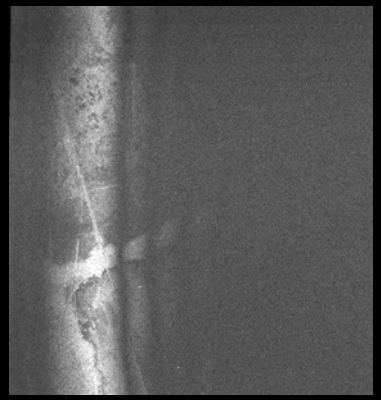
Radar Parameters

Wavelength	8 mm
PRF	1300 Hz
Bandwidth	80 MHz
Sampling Frequency	240 MHz
Flight Altitudes	8750 or 10500 m
Transmit Power	250 W

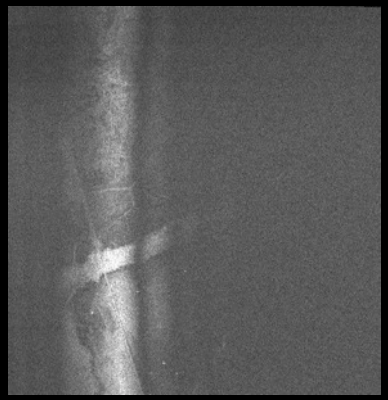
S. Hensley, *et al*

Individual Beam Imagery

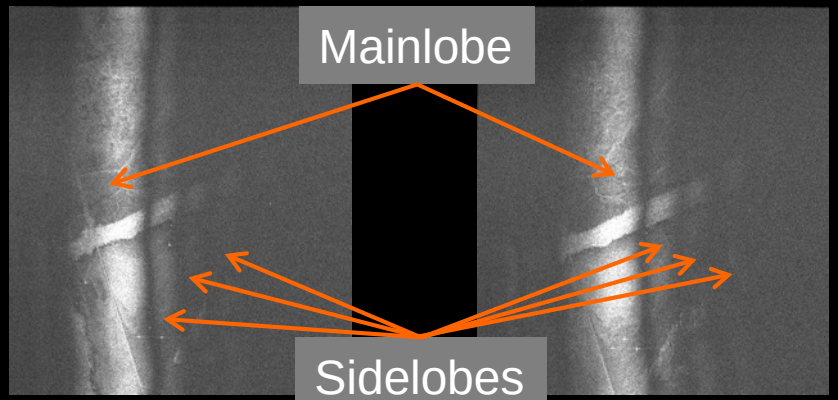
S. Hensley, *et al*



Beam 8

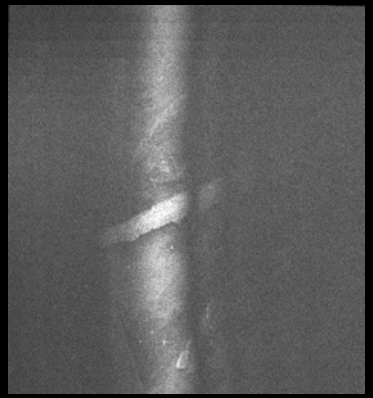


Beam 7

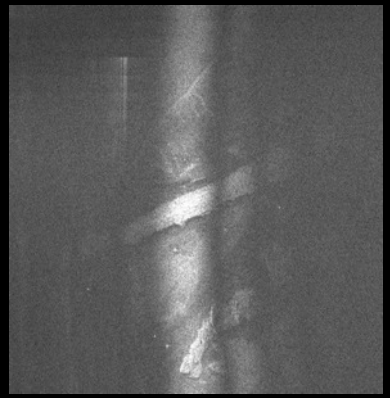


Beam 6

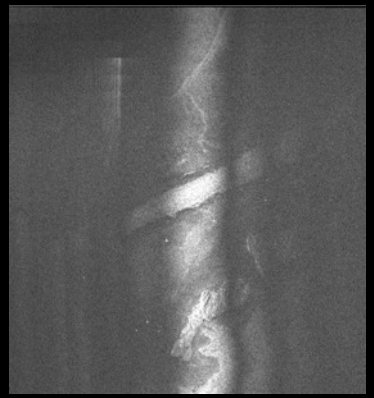
Beam 5



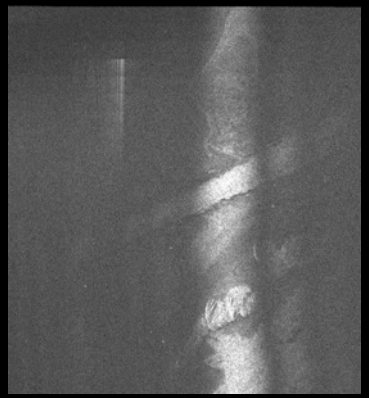
Beam 4



Beam 3



Beam 2



Beam 1

Beam Formed Imagery done on ground, manually

- Pass 11 imagery before and after beam forming.

Simple Mosaic

Beamformed Image

S. Hensley, *et al*

SweepSAR Demo image reprocessed

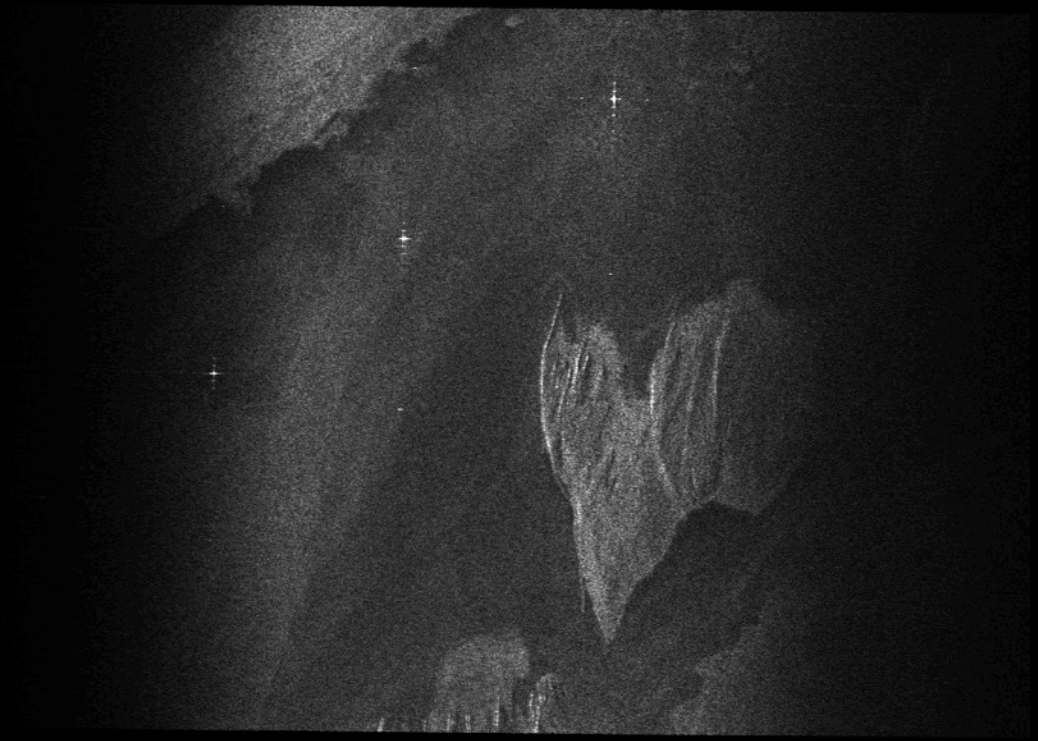


Image processed using prototype L-SAR hardware:

- Digital filtering
- Calibration
- Partial beamforming

Final image production used UAVSAR processor

Summary

NISAR L-SAR Going Forward

- NISAR will employ a novel architecture
- Individually digitized channels present both enabling advantage and unique challenges
- High-speed, on-board processing makes SweepSAR possible