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NISAR Model-Based Radar Antenna Pointing, Antenna Pattern and System Performance Evaluation

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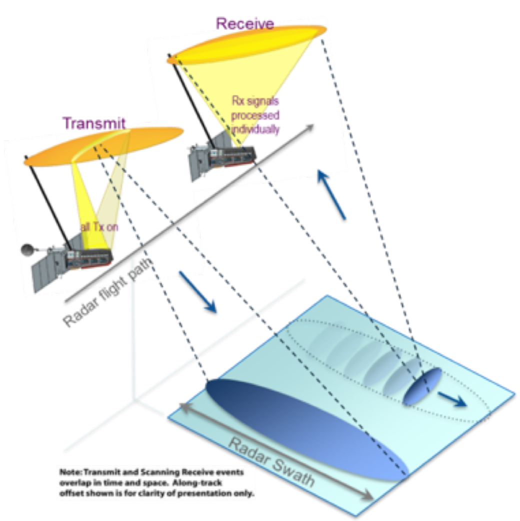
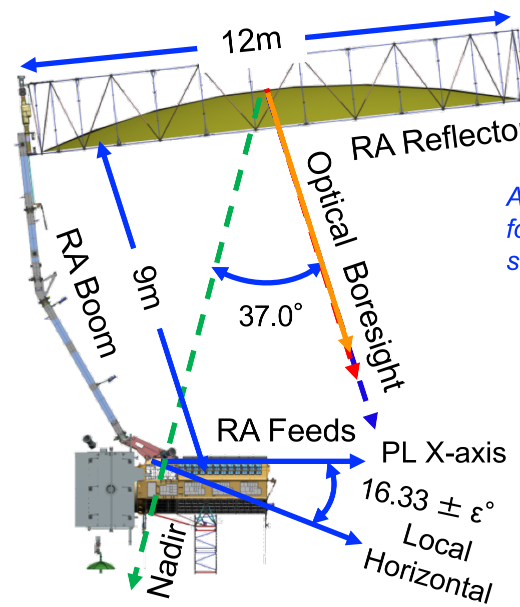
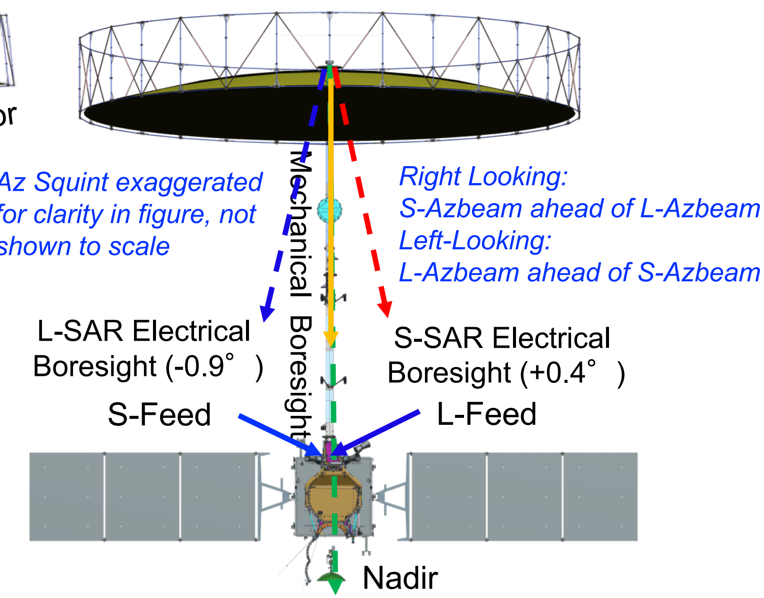
NISAR Radar Antenna (RA) and Pointing Geometry

- NISAR Radar Antenna is a 12m offset parabolic reflector with an active array feed whose center element being at focal point with 9m focal length provided by the boom. For the L-SAR (and S-SAR) system, the active array feed consists of 24(48) TRMs, 12(24) each for H-pol and V-pol, connected to 12(24) dual-pol elevation radiation feed elements.
- Adopting the SweepSAR architecture, all TRMs simultaneously transmit and radiate from the feed, and reflect by the reflector, forming a 12-beam composite fan-beam, wide in elevation, narrow in azimuth, covering 242km swath.
- SAR electrical boresights nominally aligned in elevation direction (cross-track) against a common optical boresight (pointing off nadir by 37.0°) for a usable look angle range of approx. 30 to 42 degrees off nadir.
- L-SAR and S-SAR feeds are mounted side-by-side; the L-SAR and S-SAR electrical beams are squinted in opposite azimuth (along-track) direction against a common mechanical boresight.



SweepSAR Radar Wide-Swath Fan-Beam (Right Looking)





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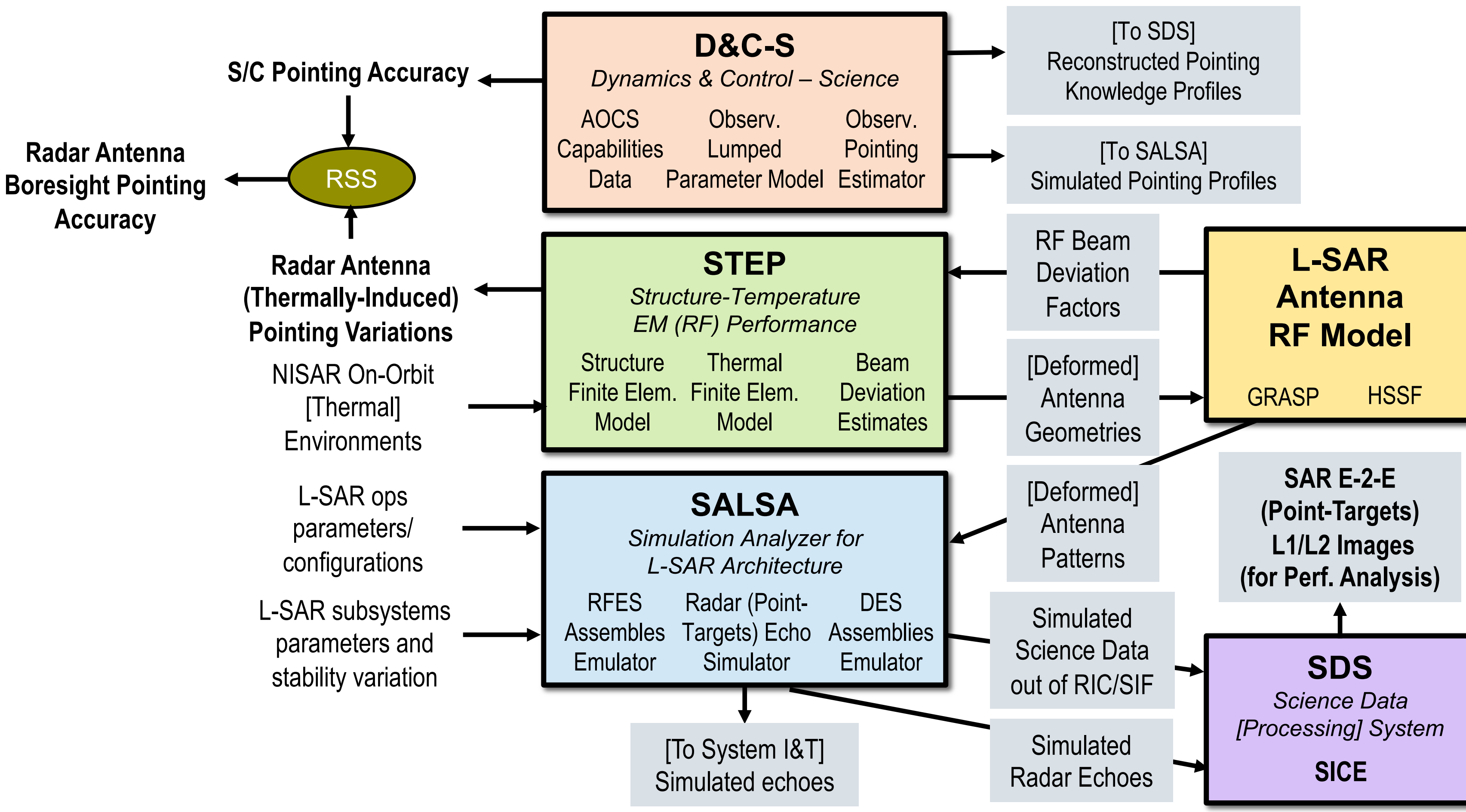
D&C-S/STEP/RA-RF/SALSA Close-Loop Modeling of Pointing Accuracy, Antenna Patterns for Systems Performance

- The shear size of deployed radar antenna makes it impractical to verify its performance (pointing, pattern, etc.) by ground testing and measurements.
- System models (D&C-S, STEP, L-SAR RA RF Model, SALSA) have been developed to perform close-loop simulations to evaluate the overall system performance.



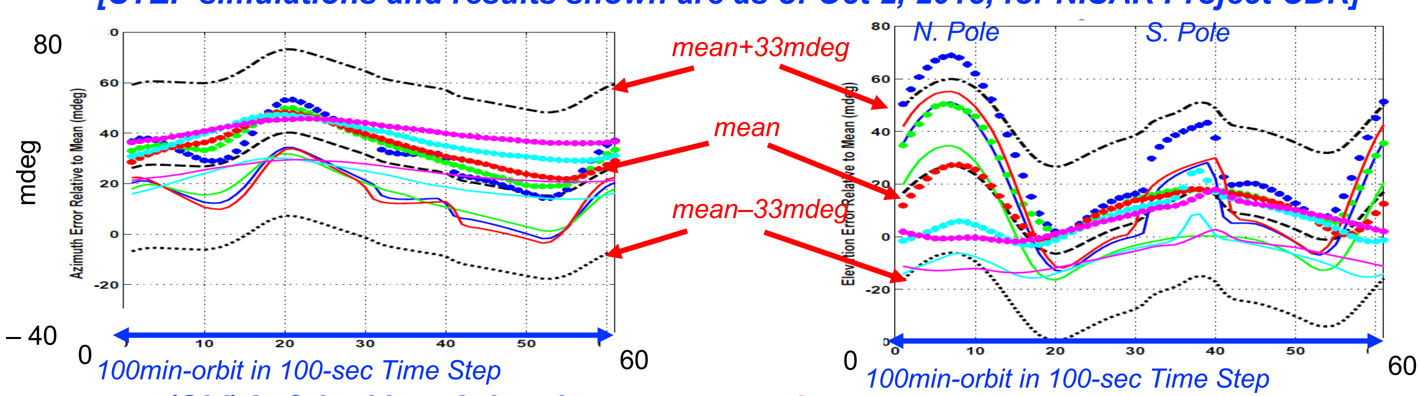
RA Repeat Pointing Accuracy Budget with STEP Modeling

- Key Pointing Requirements
  - **RA Pointing** requires pointing RA beams to pointed within **100 mdeg/axis (1σ)** of target area per ZDS profile
  - **12-Day RA Repeat Pointing** of RA beams to be within **54 mdeg/axis (1σ)** against a reference pointing profile
- **The D&C-Sci Model** includes lump model of the deployed observatory and S/C AOCS control capabilities to estimate S/C pointing uncertainties and provide ZDS pointing profile.
- Of the 12-day repeat pointing budget, **42.0 mdeg/axis** (1σ) is sub-allocated to the radar antenna, whose pointing is affected by thermal environment inducted distortion.
- **The STEP Model** includes RA antenna FEM, reflector thermal-elastic model and other component thermal properties to simulate the radar antenna pointing variation due to thermal environment changes.
- STEP simulations will be repeated using as-tested results.

Radar Antenna Pointing Accuracy (mdeg, 1σ)	Alloc.	Model Estimate Left Looking-Right Looking	% Margin
RA Reflector + Boom	**42.0**	**37.0-31.0**	**11-27**
RA Reflector	**18.0**	**25.0-18.0**	**– 39-0**
RA Boom	**15.0**	**11.0-9.0**	**27-40**

Notes: Total CBE: sum RAR+RAB (correlated), then RSS with small un-correlated terms. CBE for RAR+RAB includes MUF of 1.8. STEP results for Elevation and Azimuth vs. latitudes, for left- and right-looking, over solar beta angle ranges, over 3 years

[STEP simulations and results shown are as of Oct 2, 2018, for NISAR Project CDR]



(Old) Left looking–Azimuth RAR+RAB Only ***(Old) Left looking–Elevation***

Using SAR Data to Calibrate Radar Antenna Pointing

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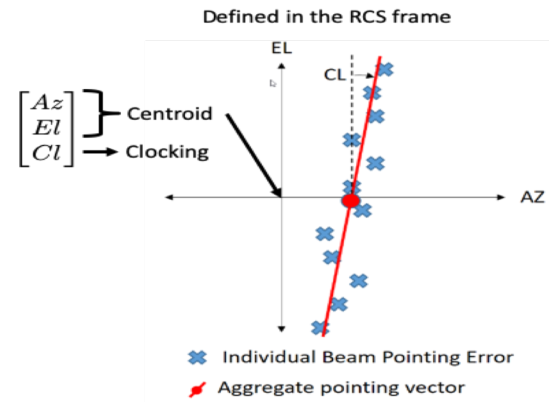
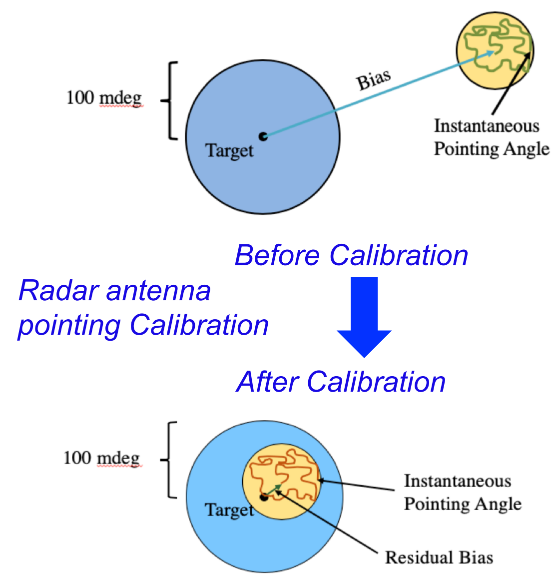
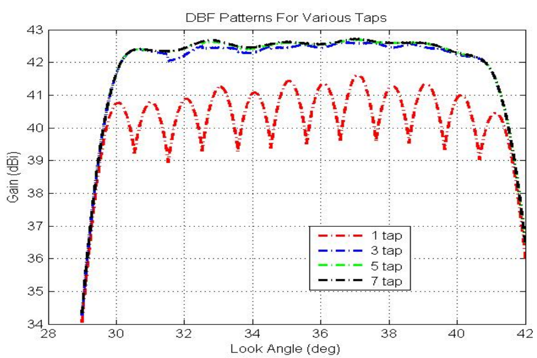
- Due to modeling fidelity and uncertainty, it is projected that RA may be off-pointed by as much as 500 mdeg, disturbed by launch and zero-G unloading.
- RA Pointing Calibration uses SAR data to estimate RA off-pointing bias; if the bias exceeds the above requirements, S/C AOCS pointing control profile be adjusted to remove the bias.
  - Azimuth electrical boresight pointing estimation employs Doppler centroid estimation in typical SAR data pre-processing
  - Nominal elevation composite beam is very broad and flat, not as amenable for estimating the elevation electrical boresight pointing; L-SAR utilizes a special configuration which would create “nulls” in elevation pattern to provide more precise electrical boresight estimate
  - For L-SAR, simulations have concluded that resulting pointing error is less than 40 mdeg.

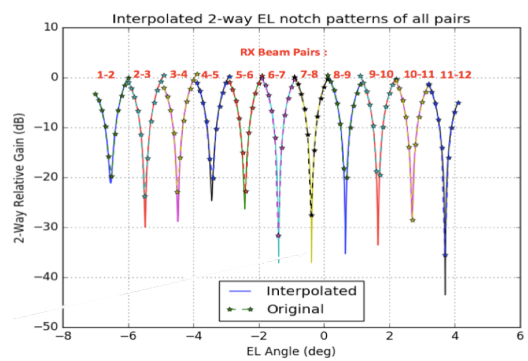


L-SAR special configured 11-null elevation pattern for L-SAR electrical boresight estimate





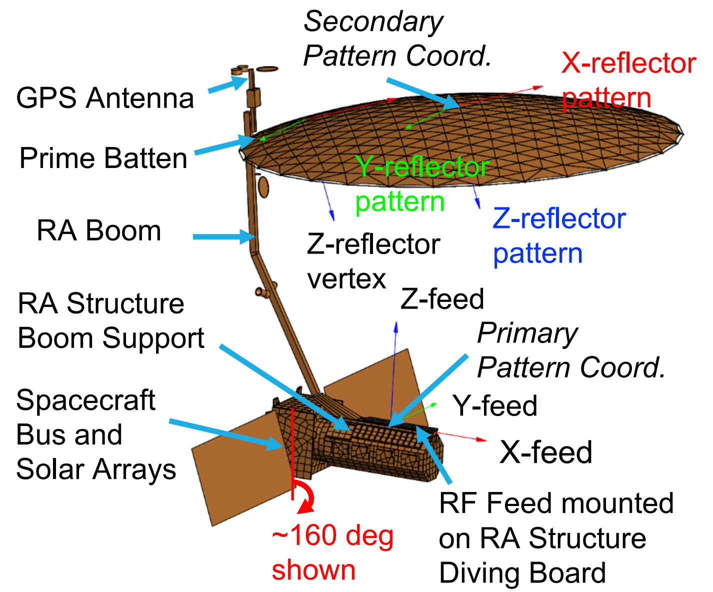
L-SAR elevation (range) pattern without DBF and with DBF, which ”flattens” the pattern and increases the gain.



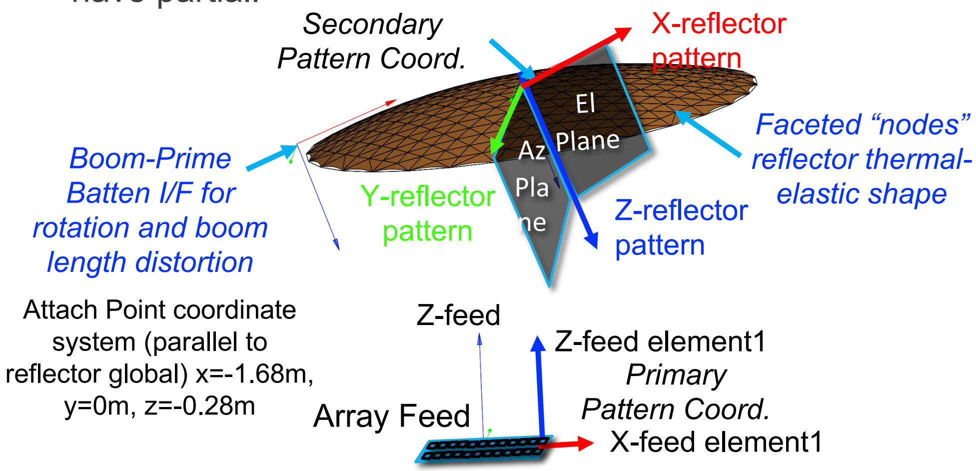
An option for L-SAR special configuration to create ”nulls” in the elevation pattern to ease the estimate of electrical boresight

Antenna RF Model and Pattern Simulations

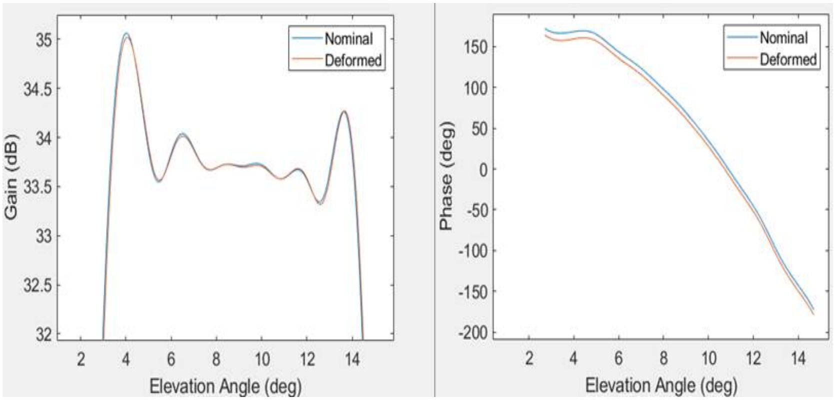
- Radar antenna [secondary] patterns not measured, relying on **RA RF Model** simulation
  - The passive array feed [primary] pattern has been simulated and measured, and is used to simulate the secondary antenna patterns; the "passive" primary pattern and secondary pattern is reciprocal
  - The STEP provides "deformed" radar antenna optical geometries under various thermal conditions for RA RF Model to simulate secondary patterns affected by thermal environment. The reflector thermal-elastic model provides faceted "nodes" reflector shape at various sun beta angles over the mission.
  - Implemented "Full GRASP Model", which simulates patterns in the presence of S/C and Instrument structure, and "No-Scatter GRASP Model", which simulates patterns without those structures. Can have partial.



RA Full GRASP Model and RF Coordinates Definition



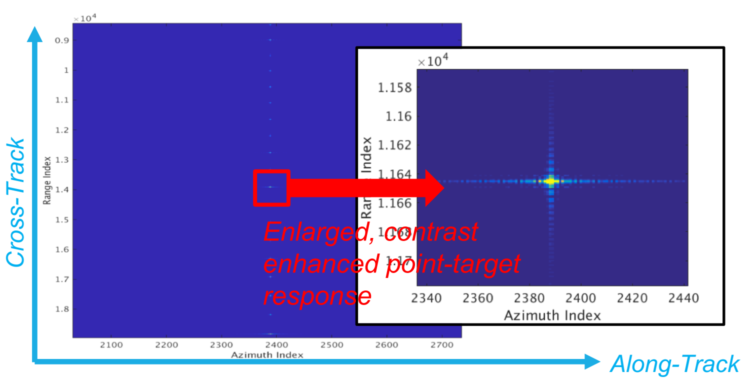
RA No-Scatter GRASP Model for Optical-Thermal Sensitivity Simulation



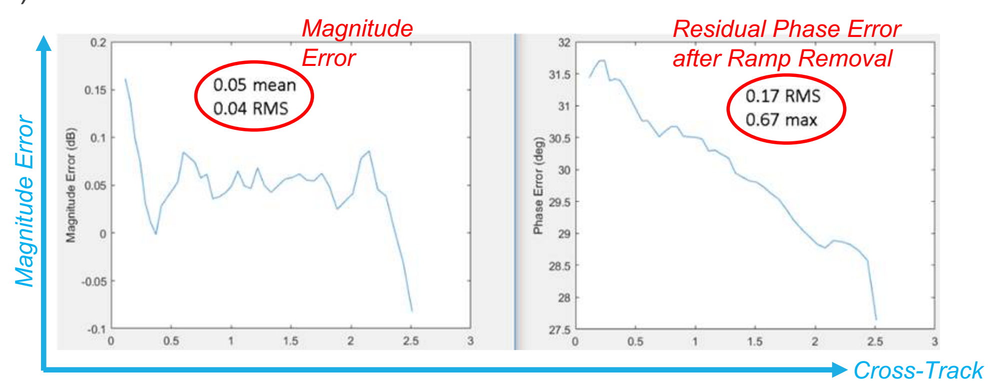
Comparison of simulated "Nominal" vs. "Deformed" elevation secondary patterns; small change in gain and phase

SALSA Evaluates System Performance and "Deformed" Radar Antenna Effect in Image Domain

- **SALSA** (Simulation Analyzer for L-SAR Architecture) is specifically designed for end-to-end SAR system performance and sensitivity evaluation; it can be configured with NISAR orbit/attitude and L-SAR ops configurations and parameters.
  - **REE** (Radar Echo Simulator) emulates RF portion of radar assembly characteristics, including TRM characteristics and antenna patterns, provided by RA RF Model, to simulate echoes from multiple point-targets. The REE also includes internal calibration signal routing and injection in the simulated echoes.
    - The REE combining the TRMs characteristics and RF Model provided "passive" patterns essentially uses "active" antenna patterns in the echo simulations.
  - **OPE** (Onboard Processor Emulator) is a software emulator of the entire digital signal processing of L-SAR Digital Electronics Subsystem, from echoes being digitized, filtered, digital beam formed, concatenated, BFPQed to "rangeline" data records
    - The OPE emulating onboard digital signal processing, including the DBF algorithms, essentially generates "effective" antenna patterns that would manifest in the radar rangelines (and later images)
- The SALSA simulated multi-point-target rangelines processed by NISAR science data processor into SLC images enables end-to-end performance and sensitivity evaluation of the SAR system with point-target signatures in the SLR images being the impulse responses (resolution, ISLR, ambiguities).



SALSA simulated rangelines of multiple-point targets processed into SLC. One simulation uses "nominal" antenna patterns and the other uses "deformed" antenna patterns.



SLC point-target response differences across the swath of simulations using "nominal" and "deformed" antenna patterns; (left) small <0.1dB magnitude difference, (right) an approximate linear phase ramp, which when removed resulting in small (<0.2°) residual phase error

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Summary

- NISAR's adopting the SweepSAR architecture employing a large reflector with active array feeds makes prelaunch ground measurements impractical, necessitating the development of system models to perform simulations for system performance evaluation and sensitivity studies.
- All the models include flight system characteristics, capabilities and parameters that can be tested and characterized during pre-launch I&T program. (As-designed parameters are used for now in the modeling but will be replaced with as-tested parameters.)
- The D&C-Science Model enables the assessment of overall S/C radar antenna pointing control errors with the STEP Model provides the radar antenna pointing uncertainties over different sun beta angles.
  - The SAR data will be used to determine post-launch antenna pointing bias in flight, and if any, will adjust the S/C AOCS to compensate (calibrate out) the bias.
- The RA RF Model simulates secondary [reflector] antenna patterns, using as-tested primary [feed] patterns. It can simulates patterns that are affected by structural elements or thermal deformed RA, provided by the STEP, which then feed to the SALSA for impact to radar system performance.
- The SALSA Model emulates radar flight system parameters and simulates radar echoes and onboard processed rangelines records. The rangelines records are processed by the science data processor into SCL images for end-to-end point-target response evaluation.
- By manipulating the system parameters to simulate rangelines, the SLC images allow evaluation of system performance sensitivities against system parameter perturbations
  - Example shows two differently deformed antenna will induce approximate phase ramp in the two repeat-pass interferogram resulting from radar antenna "deformed" differently at two different observations. The magnitude is little affected by antenna thermal deformation.
- The Models will use as-tested parameters to certify the flight system and provided projected system calibration parameters to be verified in flight.

Acknowledgement

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