



A 4 Meter 180 to 680 GHz antenna for the Scanning Microwave Limb Sounder

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June 14, 2016

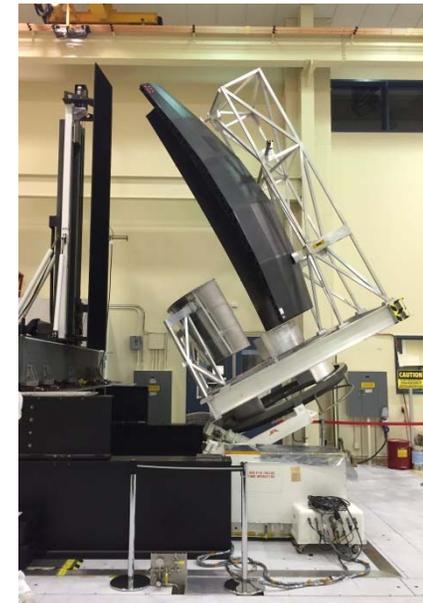
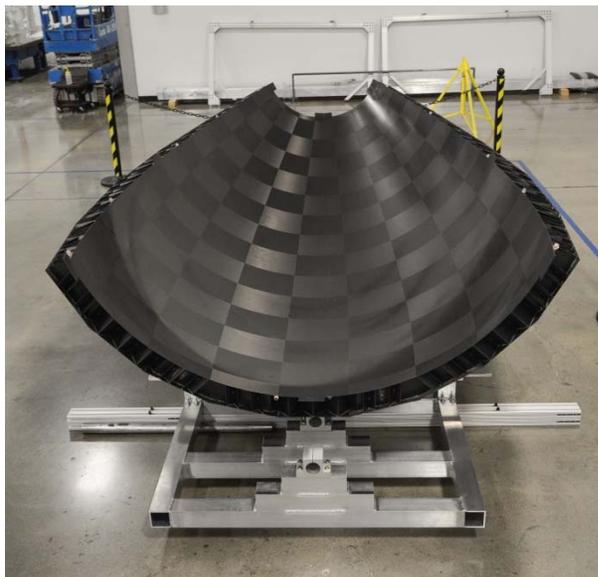
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NASA ESTO IIP-10-0021

A 4 meter 180 to 680 GHz antenna for the Scanning Microwave Limb Sounder



Richard E. Cofield

Jet Propulsion Laboratory

Earth Sciences Technology Forum

June 14, 2016





Project overview



- Overview of tasks remaining after Jan'15 ESTO briefing:

Tasks 1 & 2, Primary reflector fabrication and Thermal test, were completed per April 2014 review

- *Tasks 3 & 4 FEM correlation with Thermal tests and Breadboard Antenna /Near-Field Range Fixture (completed on Oct. 9) were addressed in the Oct.27 review*

- Task 5: Beam Patterns on Near-Field Range
 - *Most of today's talk*
- Summary





Research Team Members



- Principal Investigator: Rick Cofield, JPL
- Co-investigators
 - Paul Stek (SMLS instrument lead)
 - Nathaniel Livesey (MLS science lead)
 - Bill Read, JPL (Measurement science)
 - Mark Thomson, JPL (ALPS facility)
 - Greg Agnes, JPL (Thermal Testing in ALPS)
 - Eldon Kasl, Vanguard Space Technologies (Primary Reflector)
- Other JPL contributors [continuing](#)
 - Barry Orr (mechanical lead for breadboard antenna and NFR fixture),
 - Paul MacNeal (Finite Element Models, breadboard antenna & fixture engineering),
 - Tim Newby (Mechanical integration of breadboard, fixtures and scanner),
 - [Jacob Kooi \(NFR electronics design\),](#)
 - [Stephen Baker \(NFR beam pattern tests\)](#)





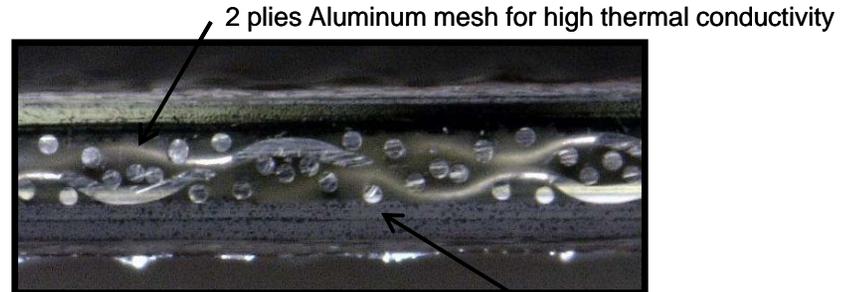
Full-Width Primary fabrication completed July 2013



Primary reflector before bonding back skin facets



Completed Primary reflector before final cure, wedge/flexure installation, and removal from mold for surface figure measurements pre- and post thermal cycle using laser tracker



Core Ribs Cross-Section

carbon fibers in cyanate resin for CTE ~0



Primary reflector surface measurement



- 12 fiducial features bonded to back of Primary front skin establish coordinate frame for comparing surface alignment data sets
- Conical nests accept 0.5 inch spheres (tooling balls or Spherically Mounted Retroreflectors (SMRs), used here with a laser tracker.

- A separate SMR is swept over the front to generate a large dataset in the coordinate system established by the fiducial spheres (one circled ○ in photos above)
- Vanguard provided contour maps and the regularized data grids in electronic form

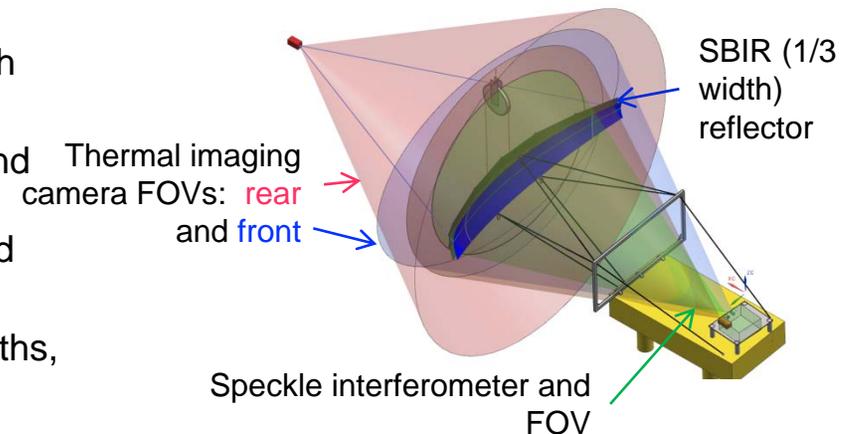


Thermal gradient tests of Primary Reflector

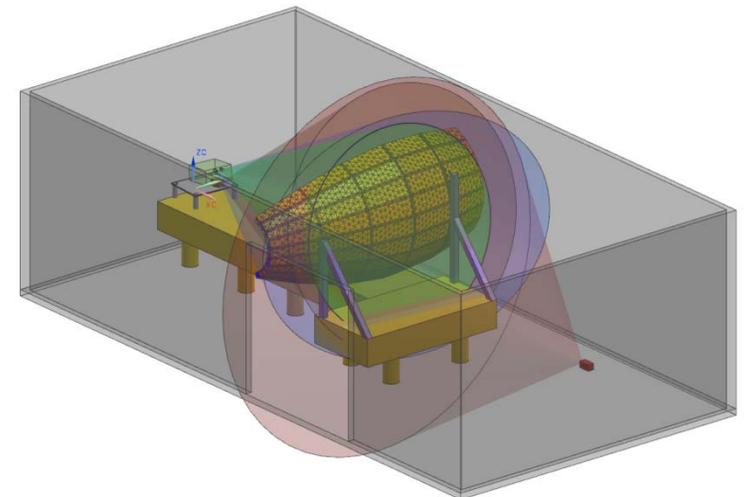


- Measure deformations under thermal gradients in JPL's ALPS facility
 - Support primary reflector in a closed test enclosure with stable environment controlled by air conditioning
 - View reflector with 2 thermal imaging cameras (front and rear) plus an Electronic Speckle Interferometer (ESPI), during transients and steady state, while heat is applied using surface contact (Minco) heaters
 - ESPI detects relative deformations at optical wavelengths, (\gg SMLS wavelengths), but gradients are \ll those expected in GACM orbit
 - Invoke linearity to infer predicted orbital performance
- ALPS I measurements (SBIR) completed June 2012
 - Custom mounts bonded to core edge to suspend reflector
 - ESPI system sensitive to 10-nm-scale vibrations; metering structure iterated to achieve stability of the metrology path
 - Correlated with FEM to within 14% of peak deformation
- ALPS II (Full-width Primary) July-December 2013
 - Reflector support via Vanguard mounts on an optics bench simplifies metering structure and reduces blockage
 - lessons learned in 1/3-width test are incorporated into the test plan for the full-width reflector

1/3-scale reflector as tested (ALPS I)

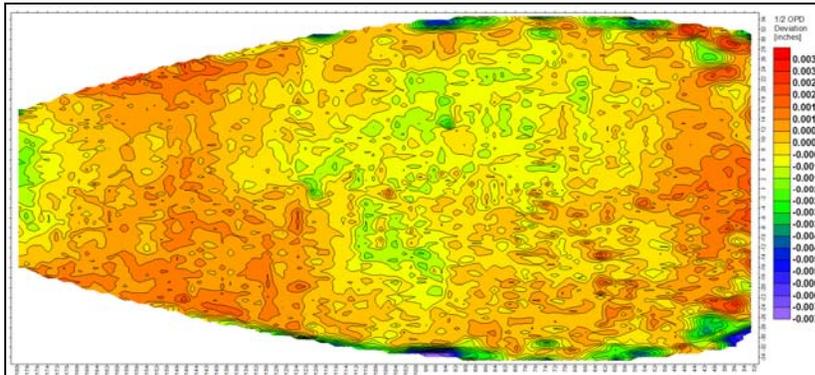


Full-scale reflector mockup (ALPS II)

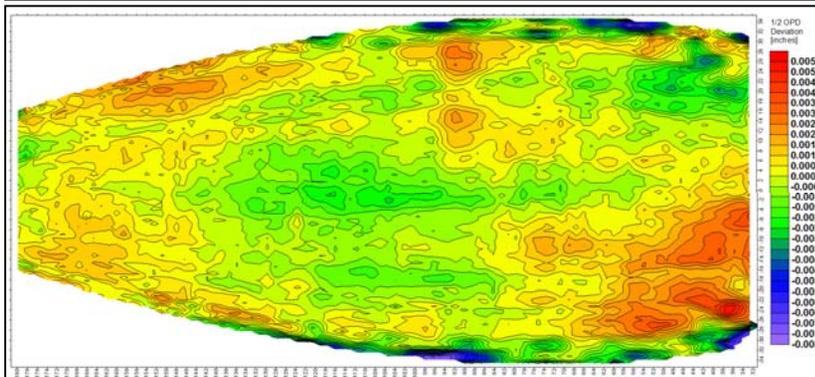




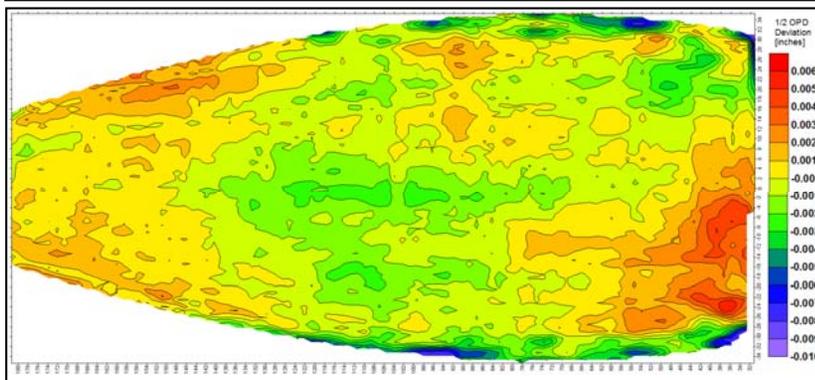
Surface contours measured by Vanguard: mold, reflector pre- and post-thermal cycling



Mold:
29 micron rms surface



Reflector pre-Thermal cycle:
37 micron rms surface*

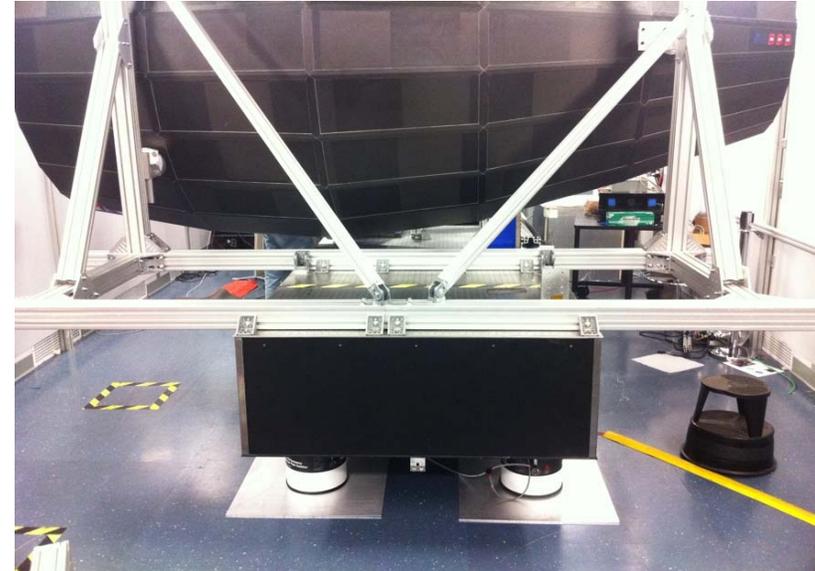
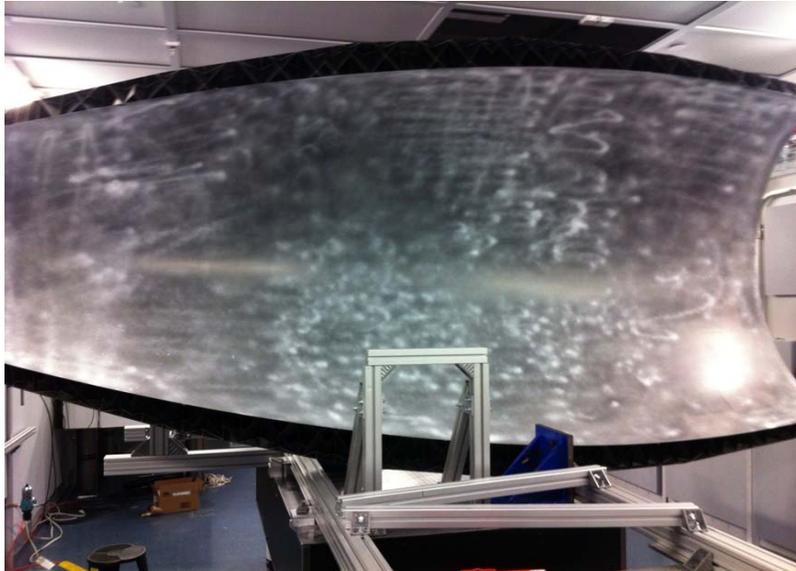


Reflector post-Thermal cycle:
43 micron rms surface*

*excluding damaged corner, see
next page



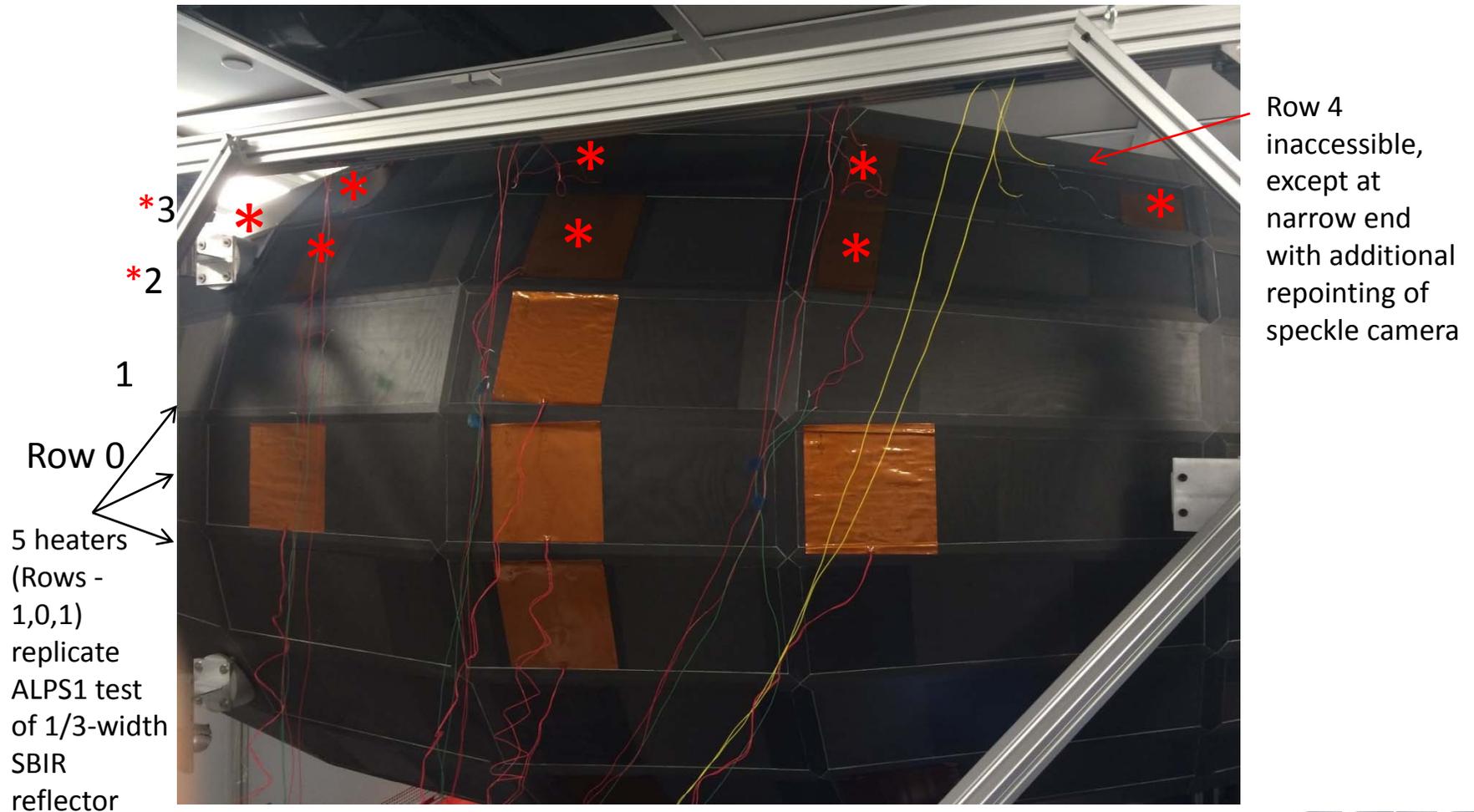
SMLS reflector mounted on kickstands in the Precision Environmental Test Enclosure (PETE)



- Front surface was sprayed with talc for speckle interferometry before installing in the PETE (talc removed after test)
- Tables are independently floated then tied together with metal frame
- Room and tables all floating (room isolation system was taken out of calibration by the MGSE and SMLS movements during installation)



ALPS 2: additional off-axis heaters to simulate orbital heat loads

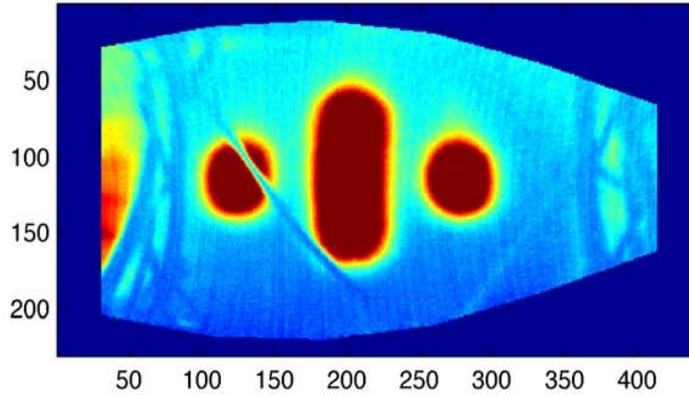




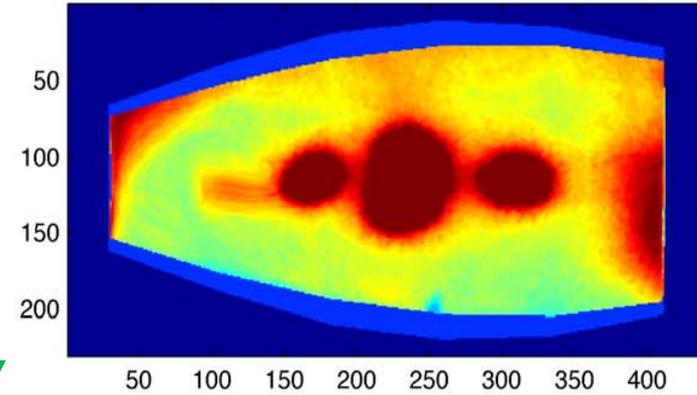
ALPS Thermal, speckle images on IIP Primary



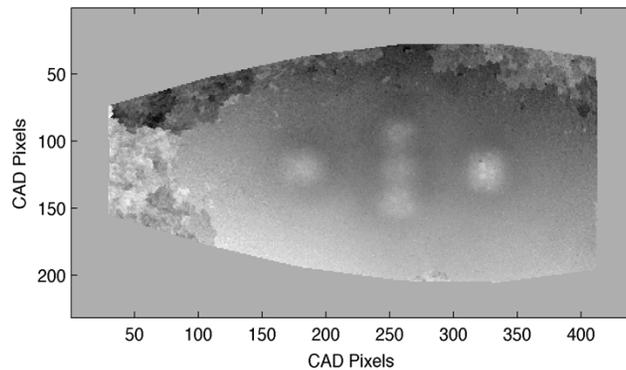
Back thermal data in CAD coords



Front thermal data in CAD coords

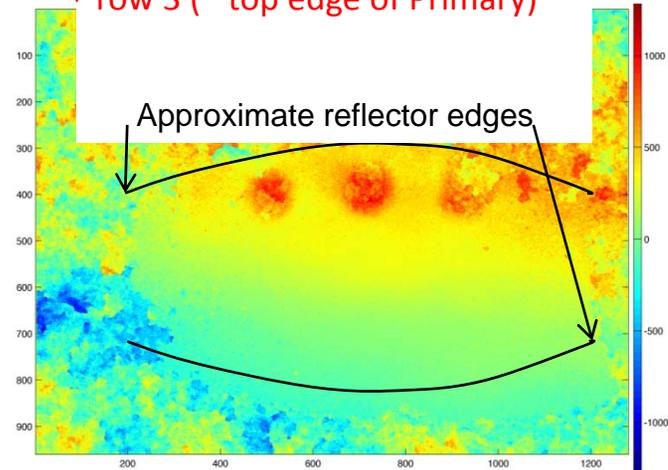


Load case: 5 heaters matching ALPS 1



(Front) speckle image unwrapped and masked

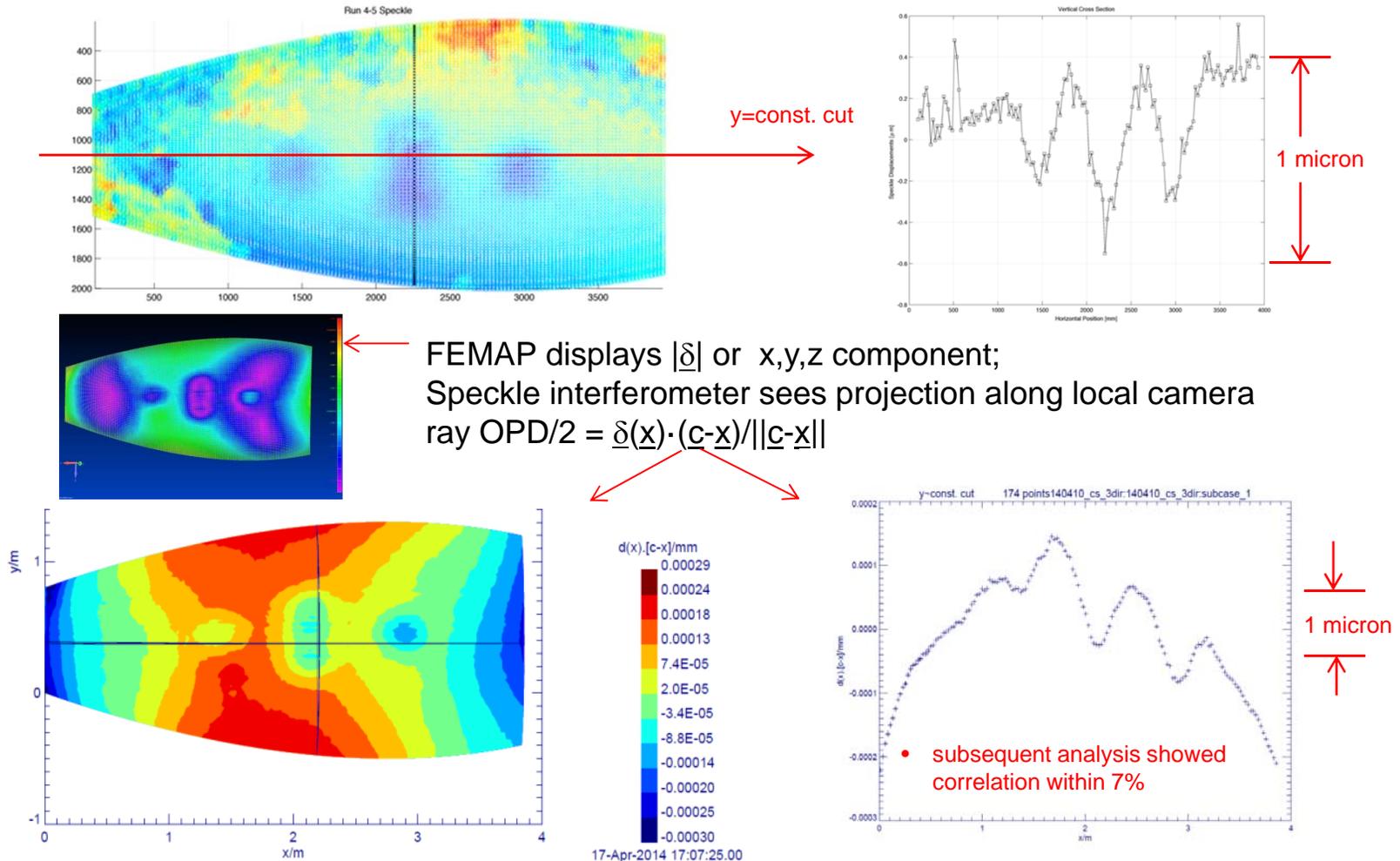
Load case: 3 inner facets in
row 3 (~ top edge of Primary)



Unregistered and partly unwrapped speckle image



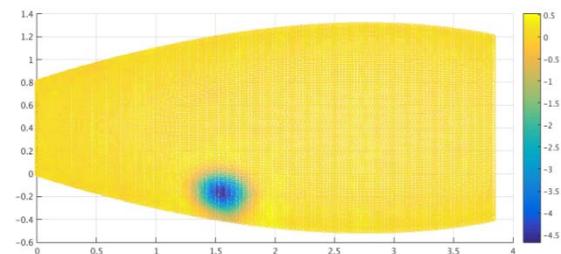
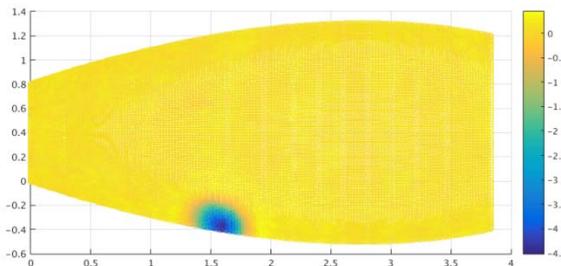
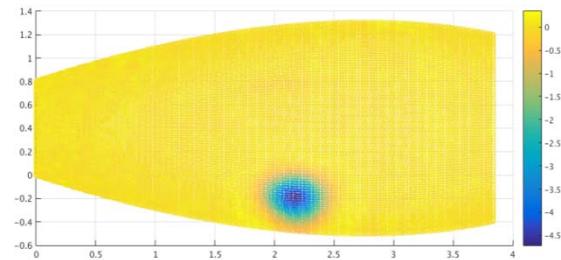
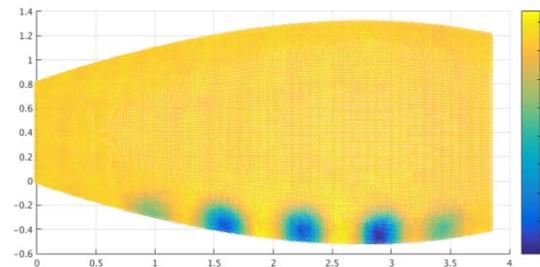
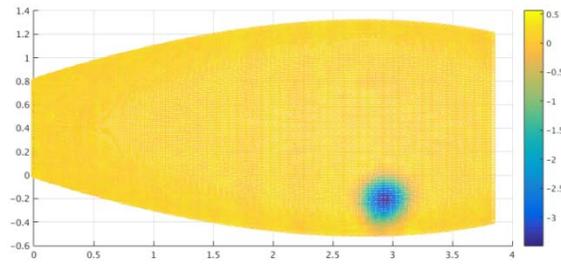
ALPS 2 Measurement/model Correlation



- Debugging FEM resolved most large low-spatial order deformation anomalies.
- Remaining ALPS 2 cases better simulate orbital asymmetry



ALPS 2 cases not yet correlated



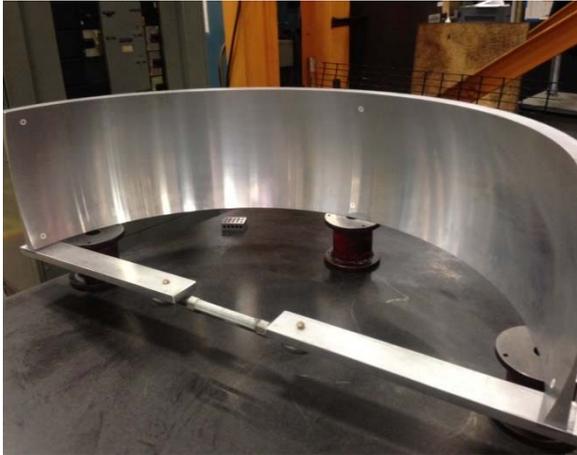
- Reflector is inverted in these front-thermal-camera images (heaters were on back top half)
- 2 diagnostic cases not shown: lateral support w/ and w/o glue

- FEM analysis has been on hold since June 2014
 - full data set SMLS.zip was delivered Apr.2 2014
 - Time-stamp issues (among the 2 thermal cameras and the speckle interferometer) hindered file associations with cases.
 - ALPS staff explained timestamps ca.5/15/2014
 - staffing prevented completion of catalog (ALPS onto other projects, SMLS onto BB antenna build)
 - Only 2 cases, shown earlier, have been registered and correlated so far: the 3-4 case used to debug FEM, and the top-heated case. Correlation was to 7%

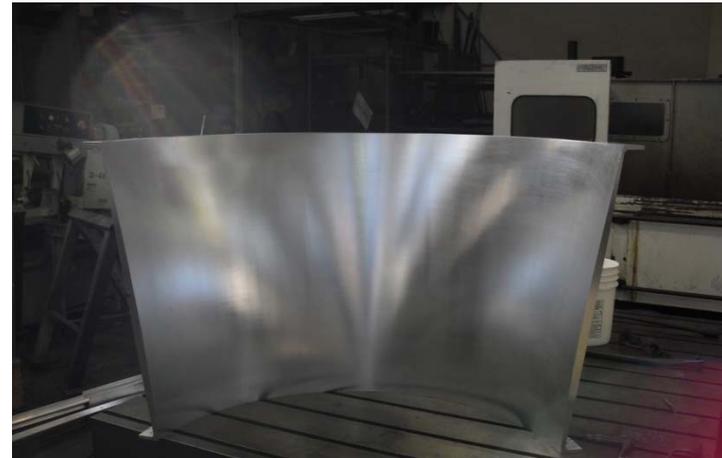
We assert that TRL has advanced based on similarity of deformations to ALPS 1 results



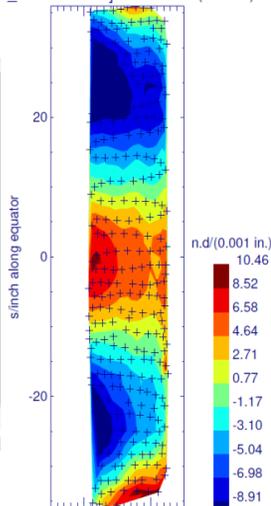
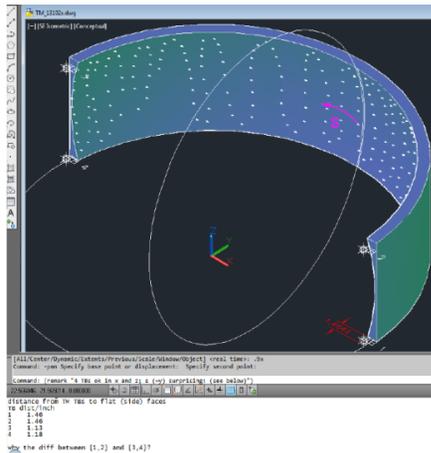
Breadboard Secondary and Tertiary Reflectors



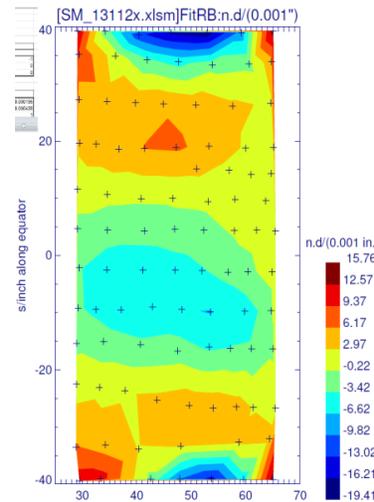
Tertiary with spreader bar for match-drilling



Secondary, pre-ship



Tertiary surface accuracy within ± 0.01 inch

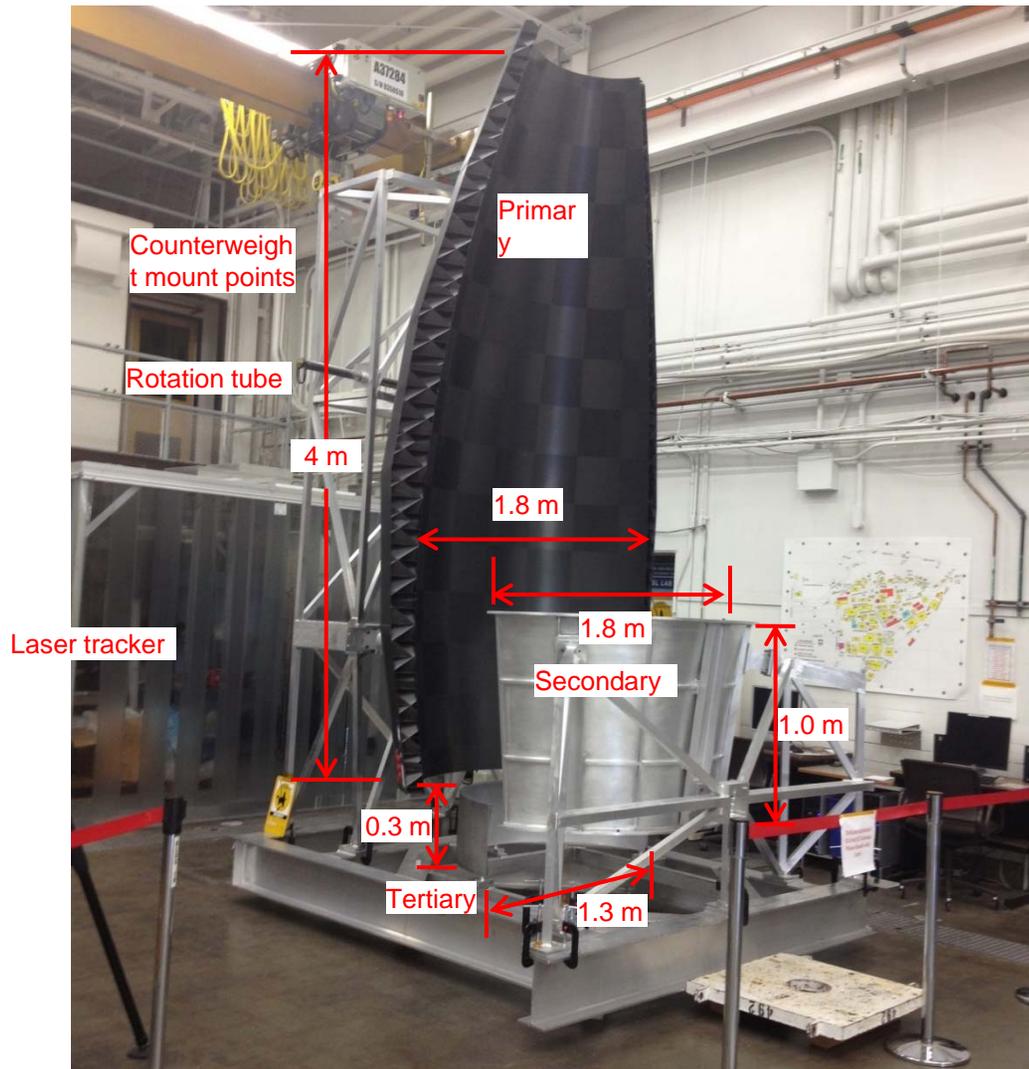


- Free-standing surface accuracy within ± 0.02 inch (0.0055 inch rms)
- With adjustment at mounts, alignment improved to ± 0.004 inch
- Surface confirmed April 2014 at JPL within 0.0046 inch rms





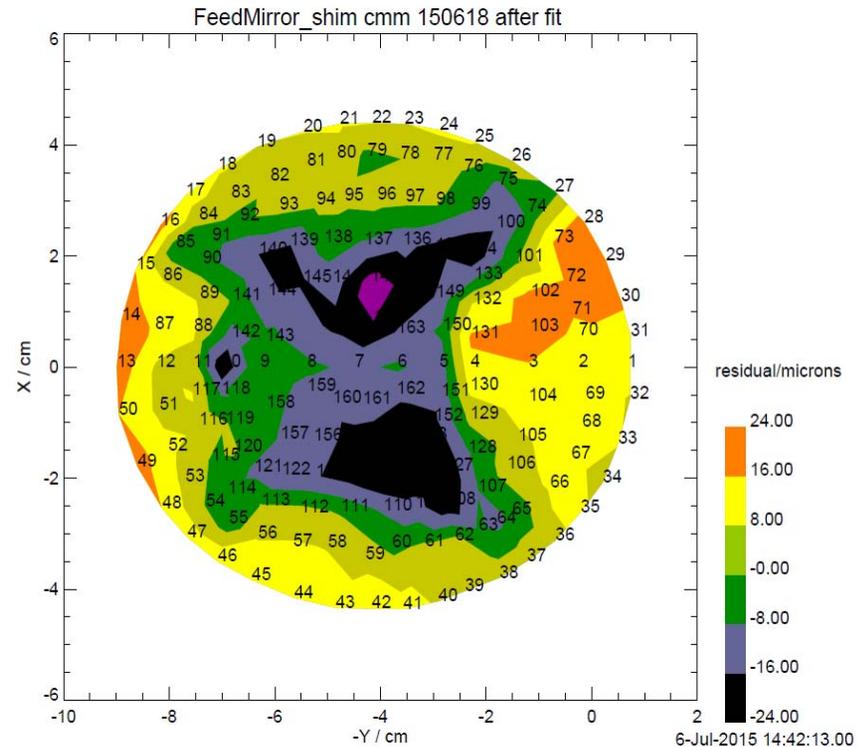
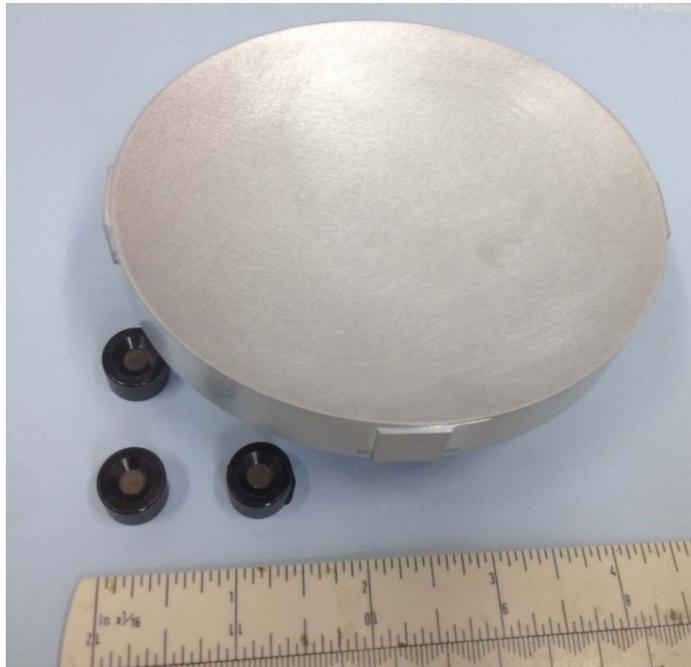
Breadboard antenna: assembly and alignment



- Measured alignment using laser tracker and spherically mounted retroreflectors (SMRs)
- SMRs on each reflector verified edge contour (hence surface figure) last measured by vendor before delivery
 - including all 12 on Primary before installation; subsequently used lower 6 to align
 - Secondary figure directly measured after removing over-constraint by support
 - Relaxed figure very close to vendor data
- Subsequent steps:
 - Completed shimming and alignment June 2014
 - Estimate residual $\frac{1}{2}$ -path error, due to surface figure and final alignment, as 0.5 mm = $\lambda/5$ at 120 GHz: acceptable for beam patterns)
 - Moved to 306 for final assembly and pattern tests



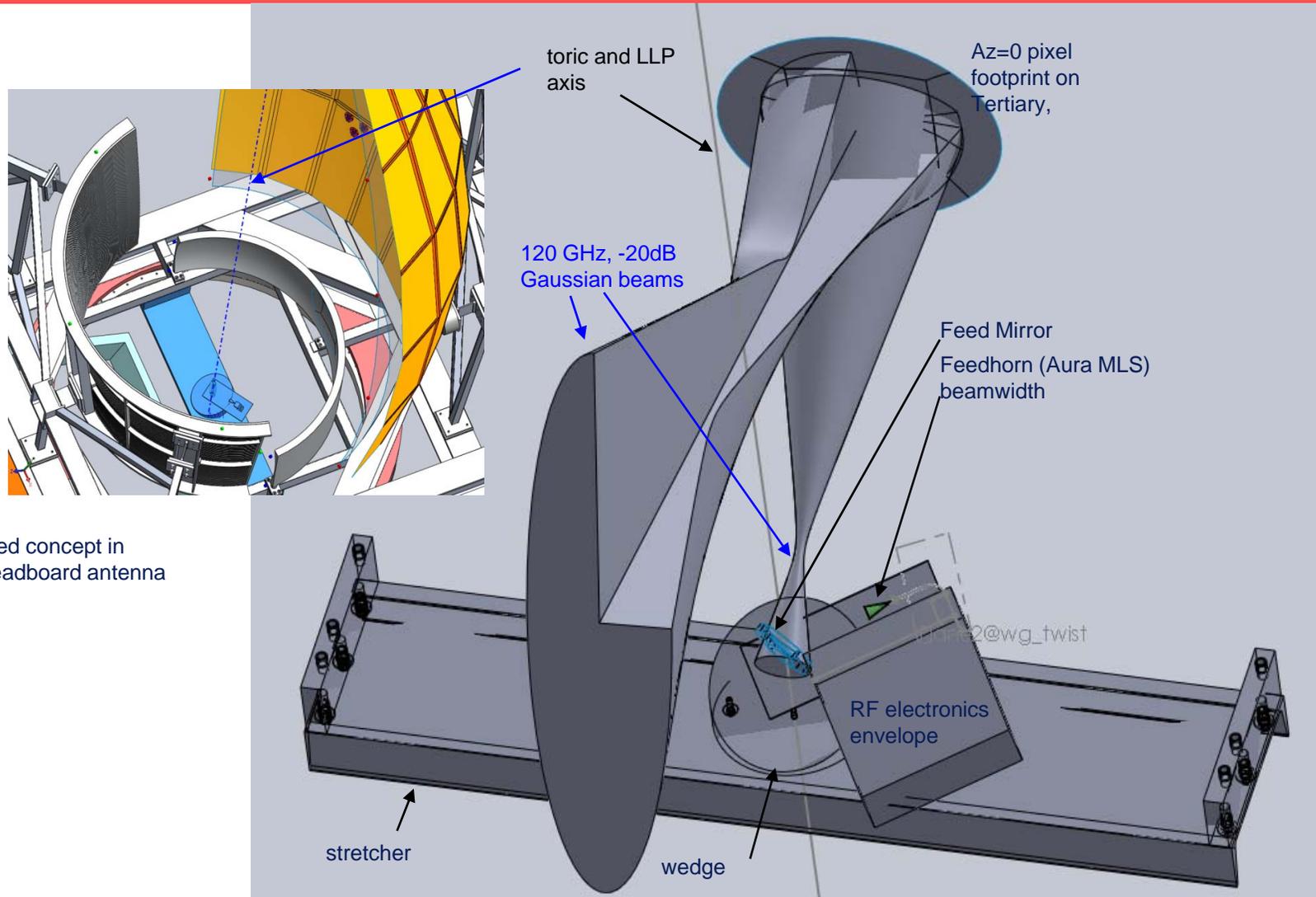
Feed Mirror surface and fiducial inspection result



- Feed mirror and Fiducials (SMR nests) before bonding and CMM inspection,
- 3 shims (thickness 0.006 to 0.015 inch) reduce as built surface error of 150 micron rms to 12 micron rms shown here. Thicknesses were incorporated in feed bracket fabrication.
 - cf. 25 micron required for 120 GHz
- also measured Fiducials (SMR nests) for reference aligning to horn and antenna.



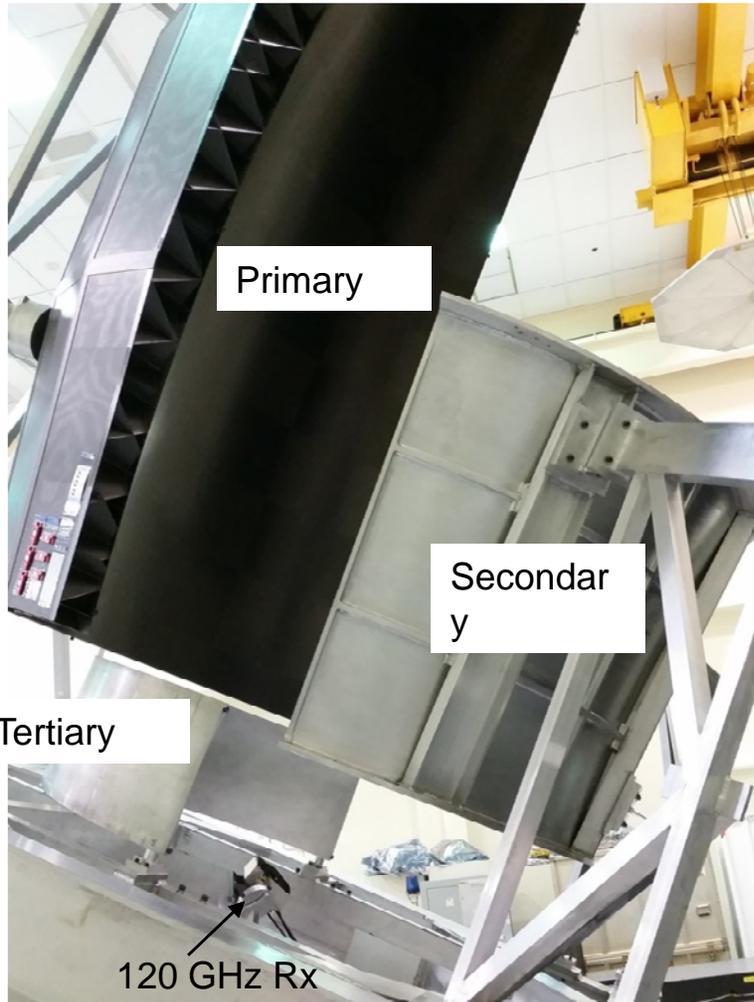
Feed system design



Feed concept in breadboard antenna

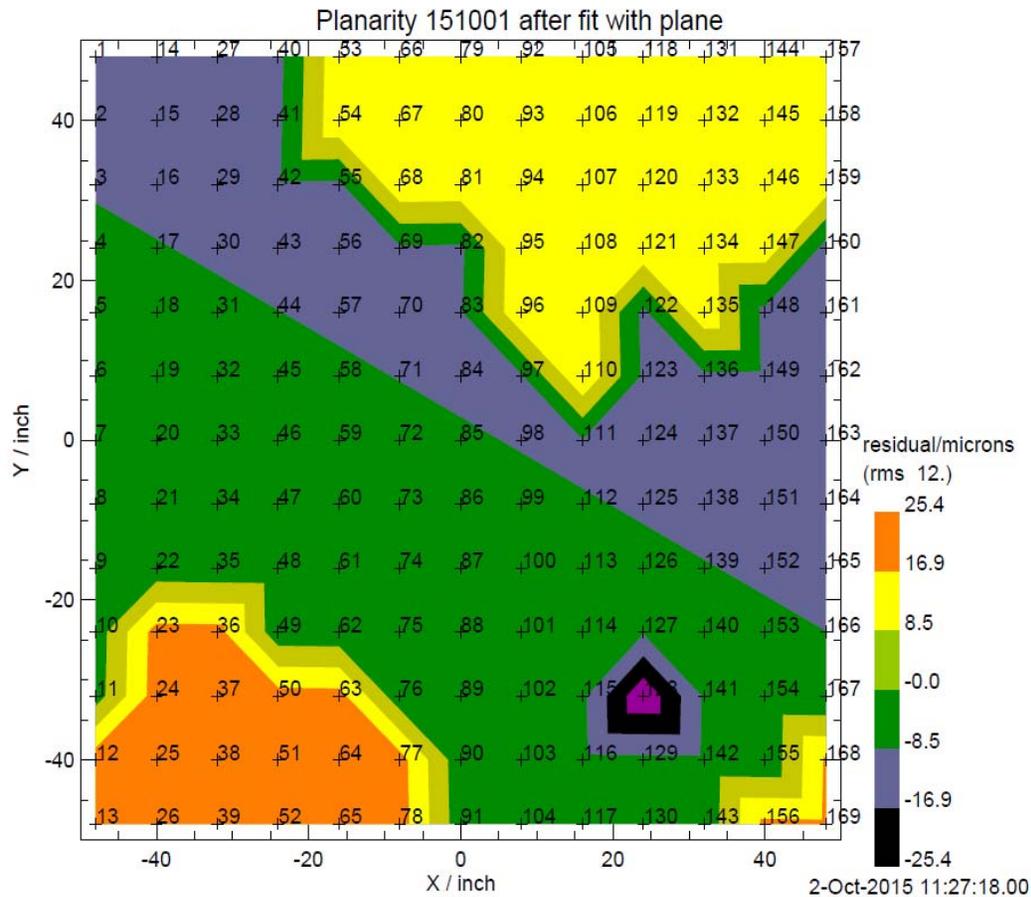


feed in SMLS breadboard antenna





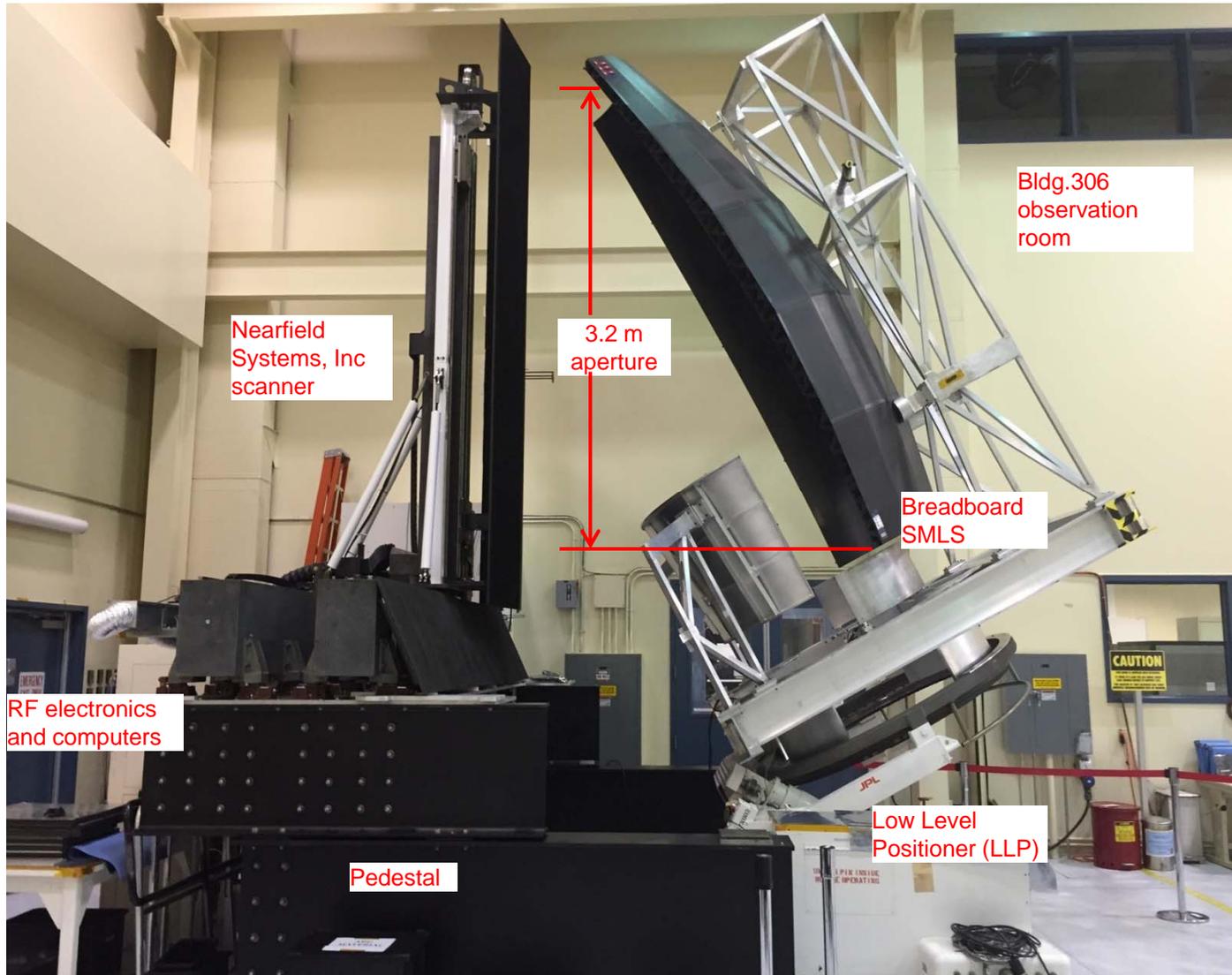
Planarity improved after 2nd round leveling



- 12 micron planarity acceptable for 120 GHz patterns
 - Improvement could be due to
 - better temperature stability
 - pedestal stiffening measures
 - colocation of NSI laser on seismic pad (unlike 1st measurement)
- We monitor planarity through upcoming patterns
 - and apply software corrections (“K-correction”) in post-processing of Near-field data if required.

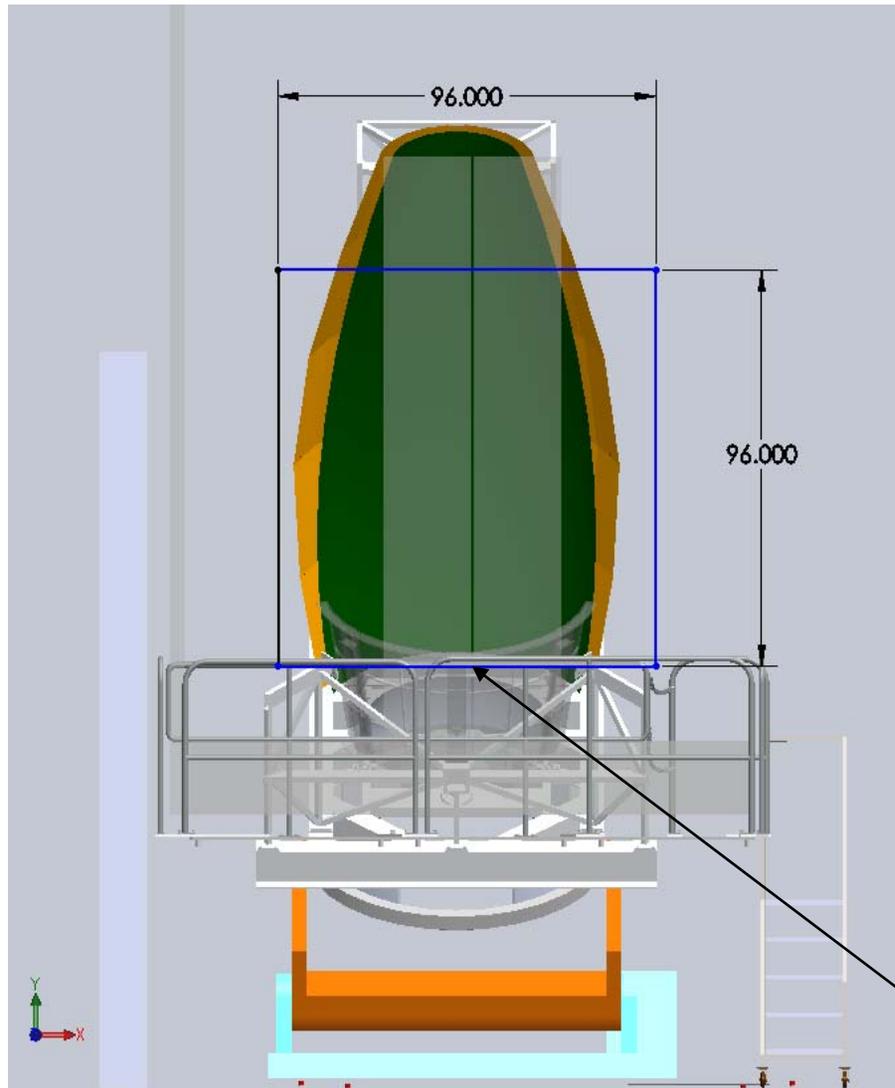


SMLS breadboard in Near Field Range





As-built scan range

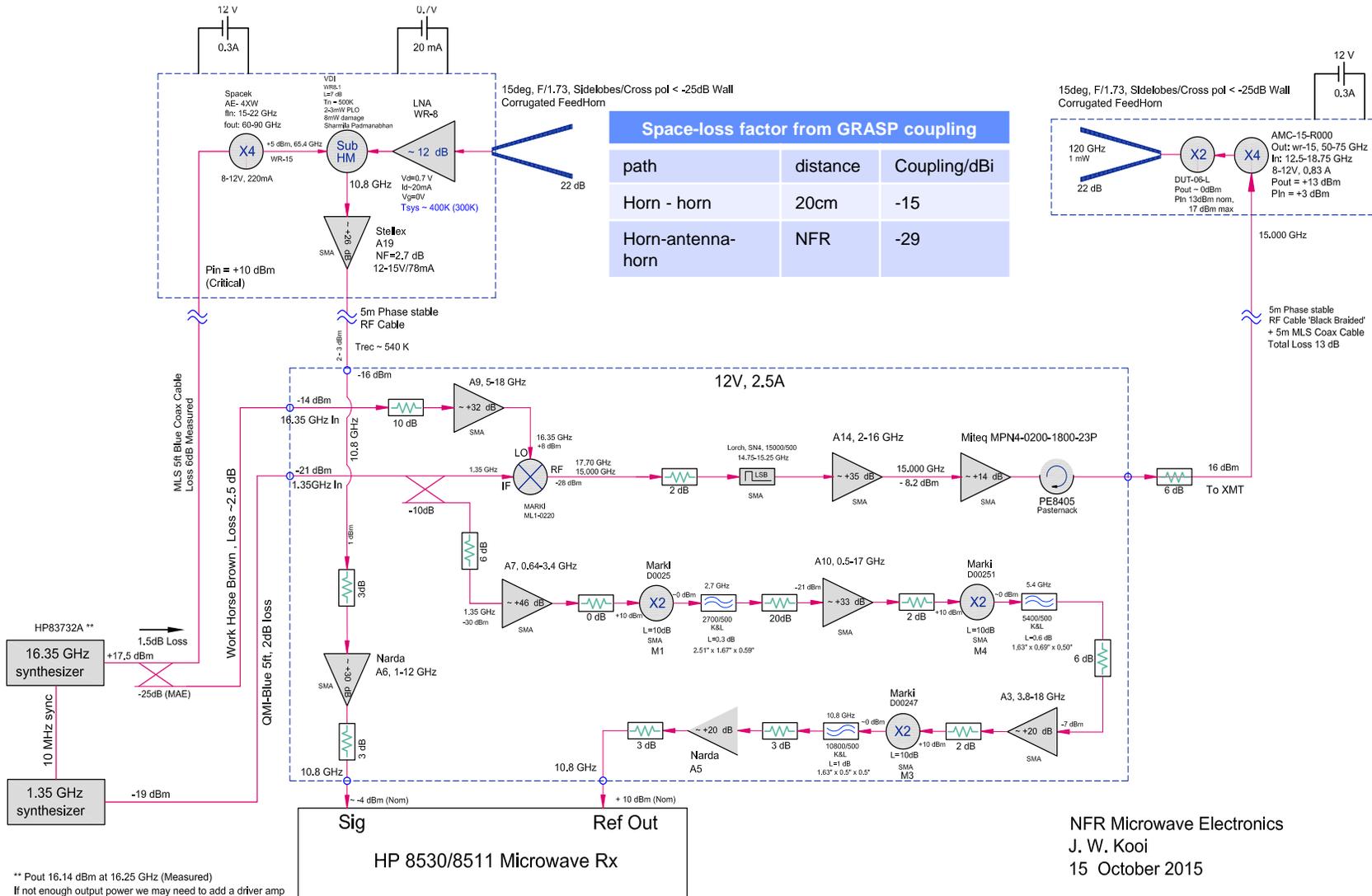


- 8x8' scanner covers only lower 2/3 of SMLS aperture
- We can extrapolate performance through entire aperture by using the Physical Optics model
 - 5.9' width of reflector is within scan range, esp. since illuminated width is much less for a given pixel
 - 3 scan positions enabled by wedge feed support (+30°, 0° shown and -60° Azimuth offer sufficient sampling of $\pm 65^\circ$ design coverage

higher eyebrows expose 6.5 inch margin below Primary

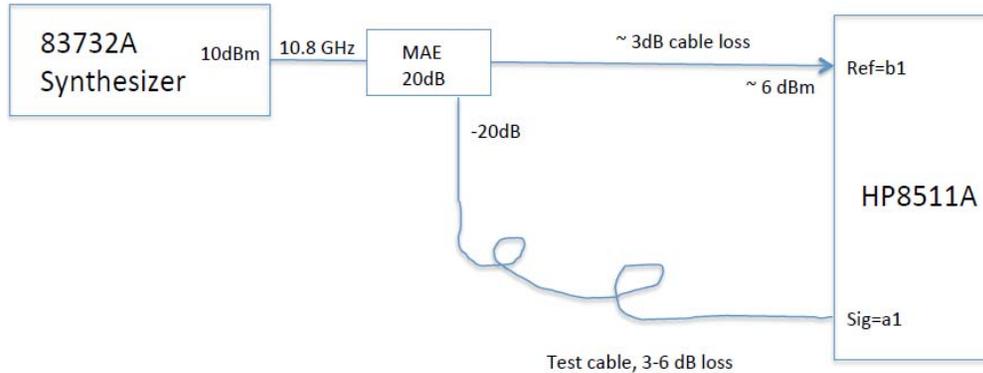


Near-Field electronics block diagram



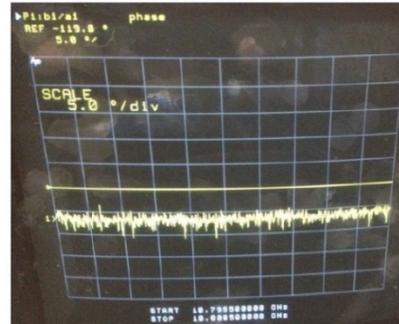
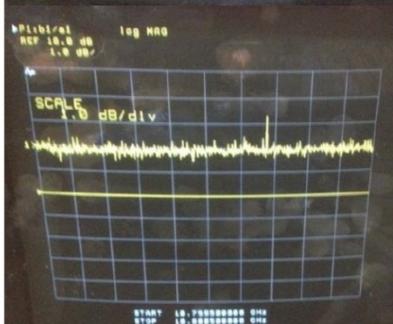
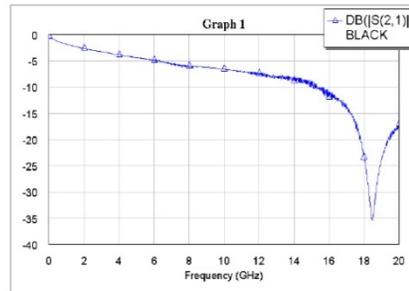


repeated RF electronics stability tests in rack **JPL**

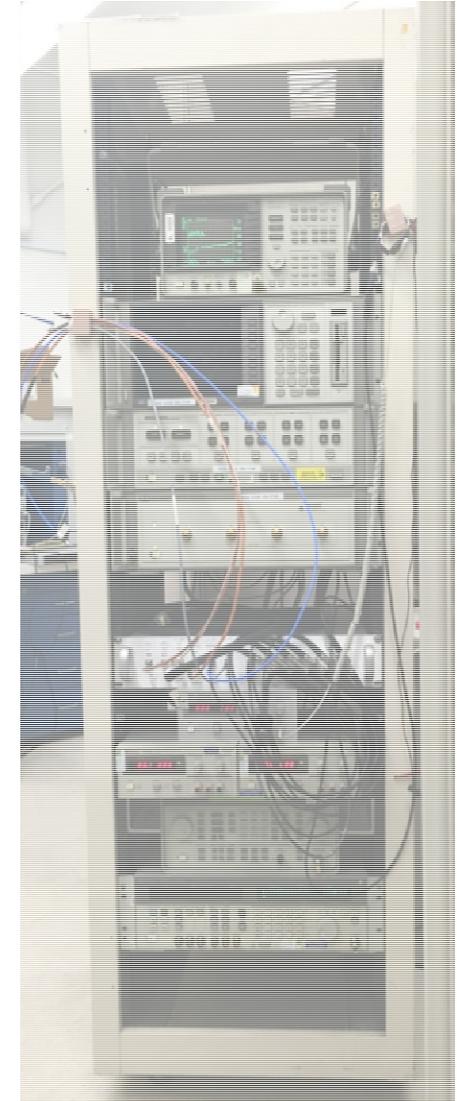


Loss 6.9 dB @ 10.8 GHz
(0.46 dB/ft)

15 ft Black Braided Flex Coax Cable

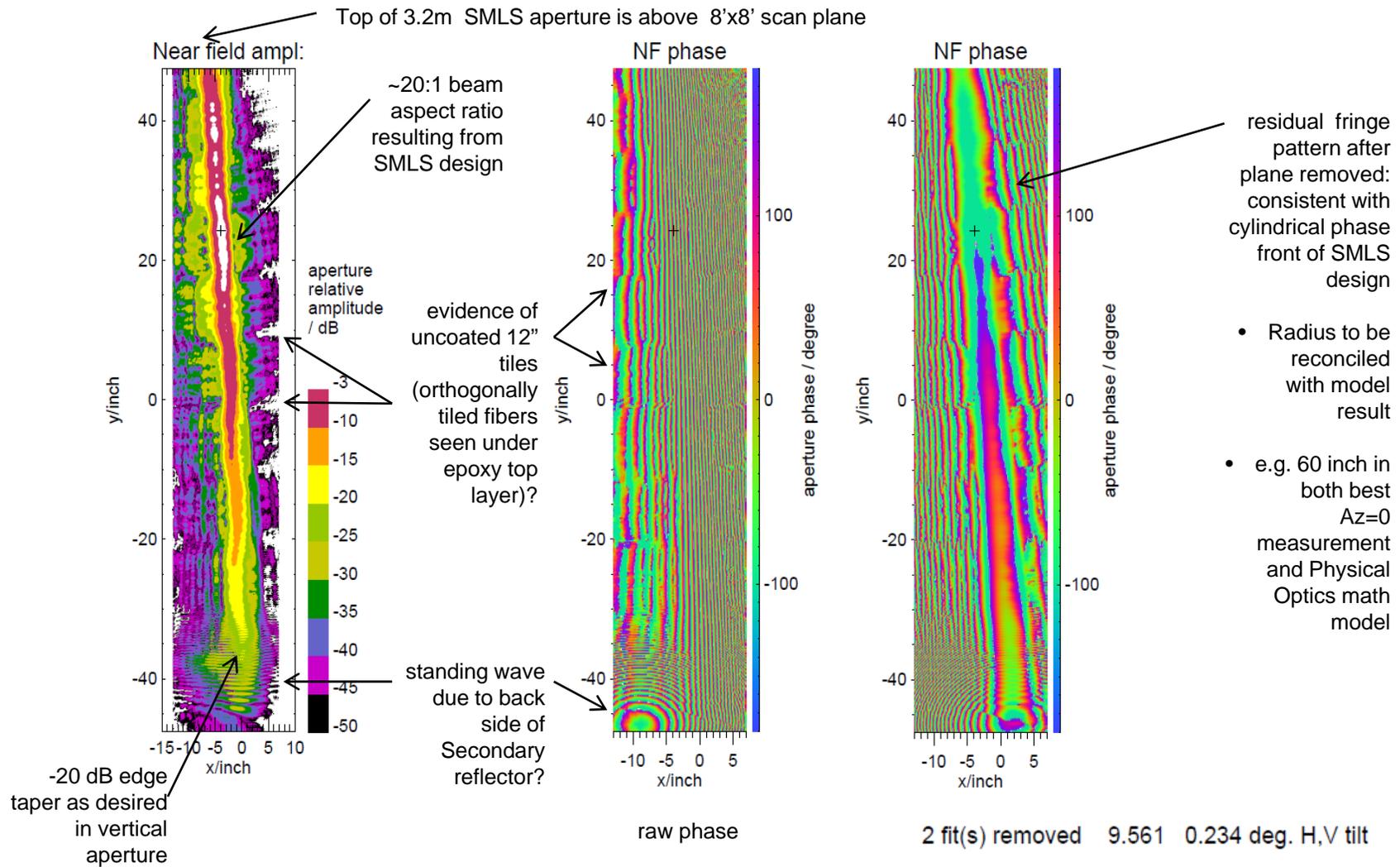


- HP receiver-limited stability, all cables, +6dBm ref (b1):
- ± 0.15 dB Ampl.
 - $\pm 1.5^\circ$ Phase
 - found same $\pm 1.5^\circ$ Phase stability w/ NFR cable and 1' horn separation (totally limited by HP 8530/8511 receivers)





120 GHz Near field patterns, center azimuth pixel



Large tilts, in both phase and amplitude maps, could result from antenna mis-pointing (Low Level Positioner has no fine control) or misalignment residual from hole slop in the feed mirror and horn (these were not aligned).

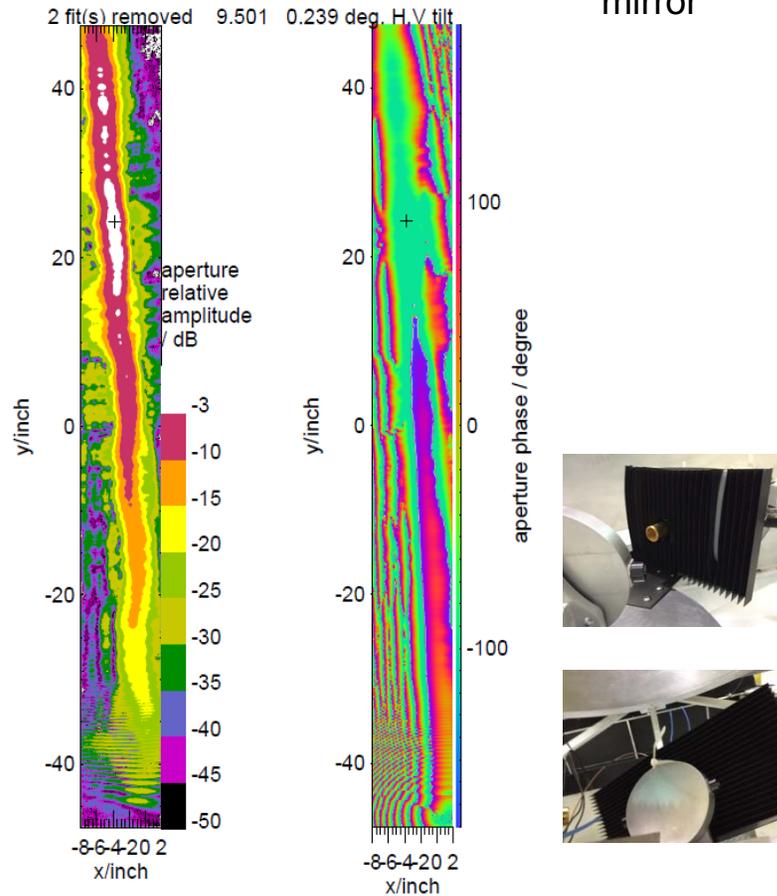




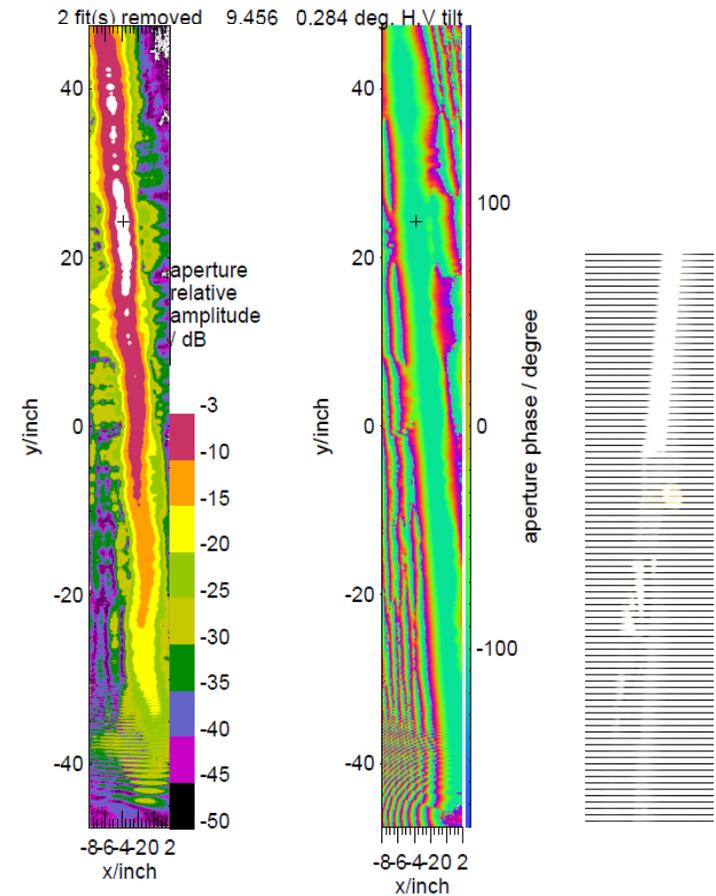
Critical absorber positions



on receiver box face, & behind Feed mirror



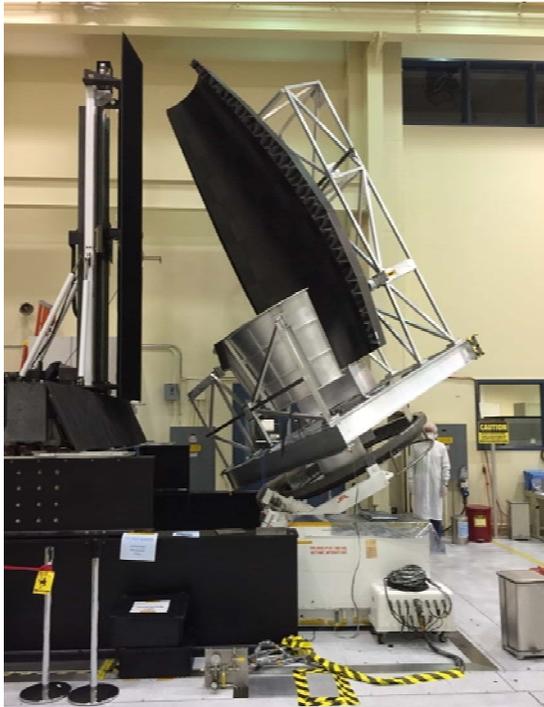
same, plus on Xmitter horn (final config)



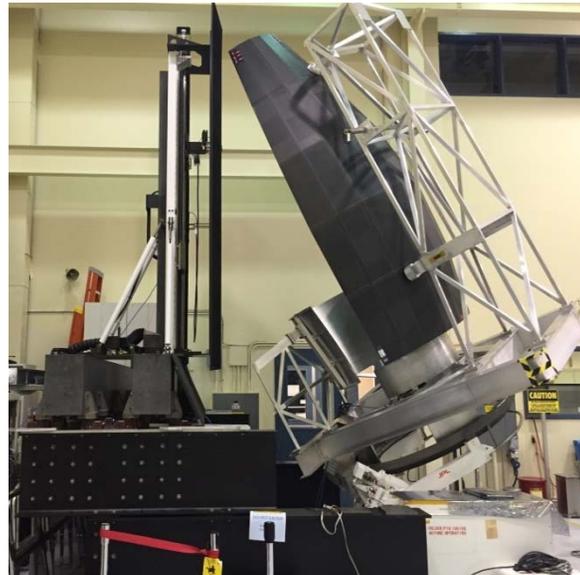
Stability: 0.98 dB drift in 10.5 hr,
reduced to 0.05dB, < 0.5° phase in 10 min. intervals (Motion Tracking Interferometry)



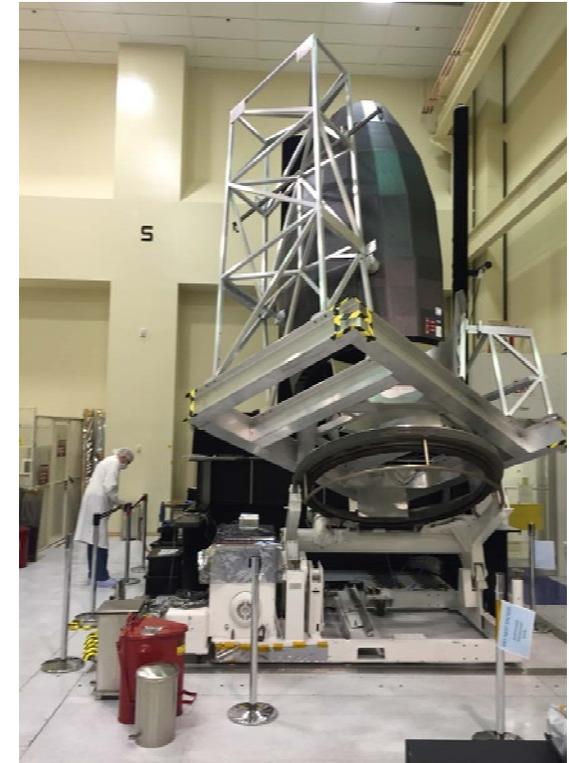
Position at 2 Azimuths following Azimuth 0°



LLP Azimuth +30°

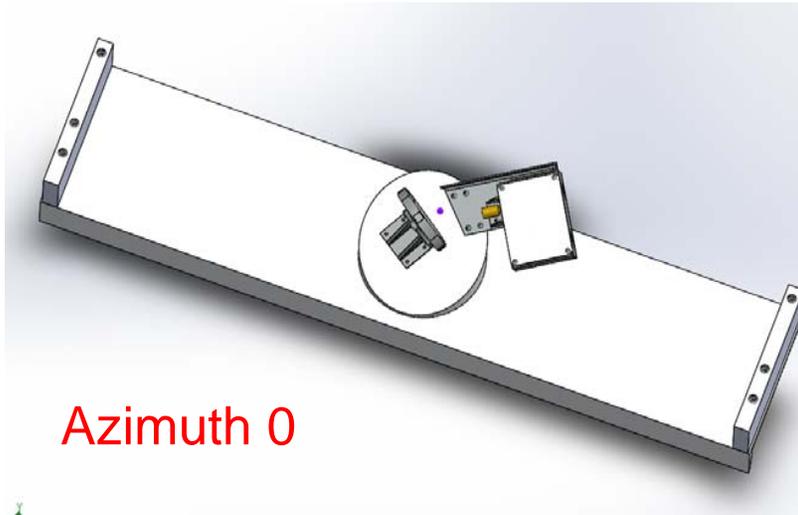


LLP Azimuth -46°; views from East and North

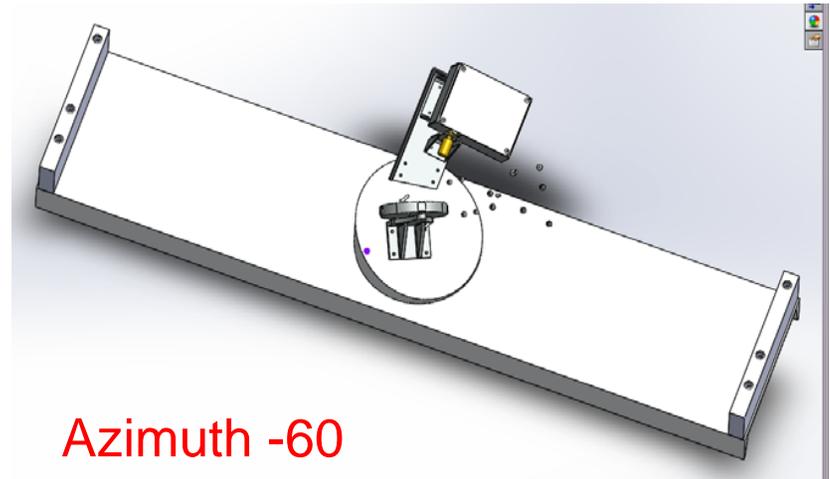




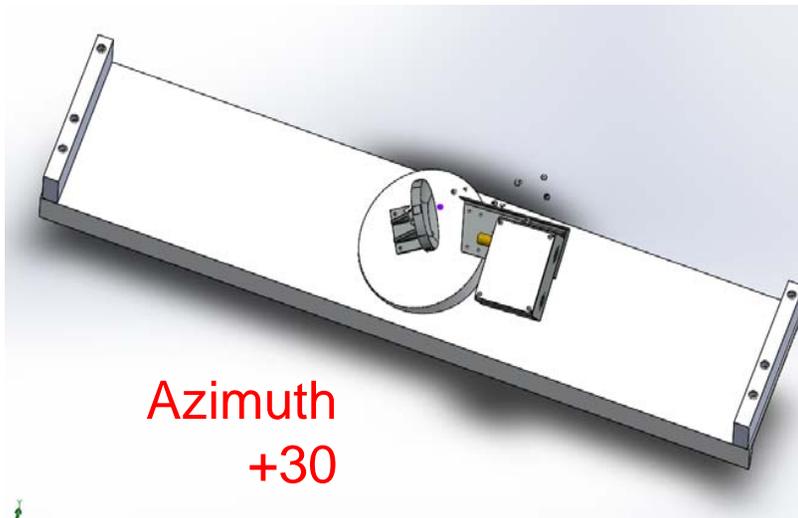
Wedge Azimuth options



Azimuth 0

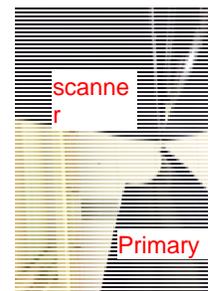


Azimuth -60



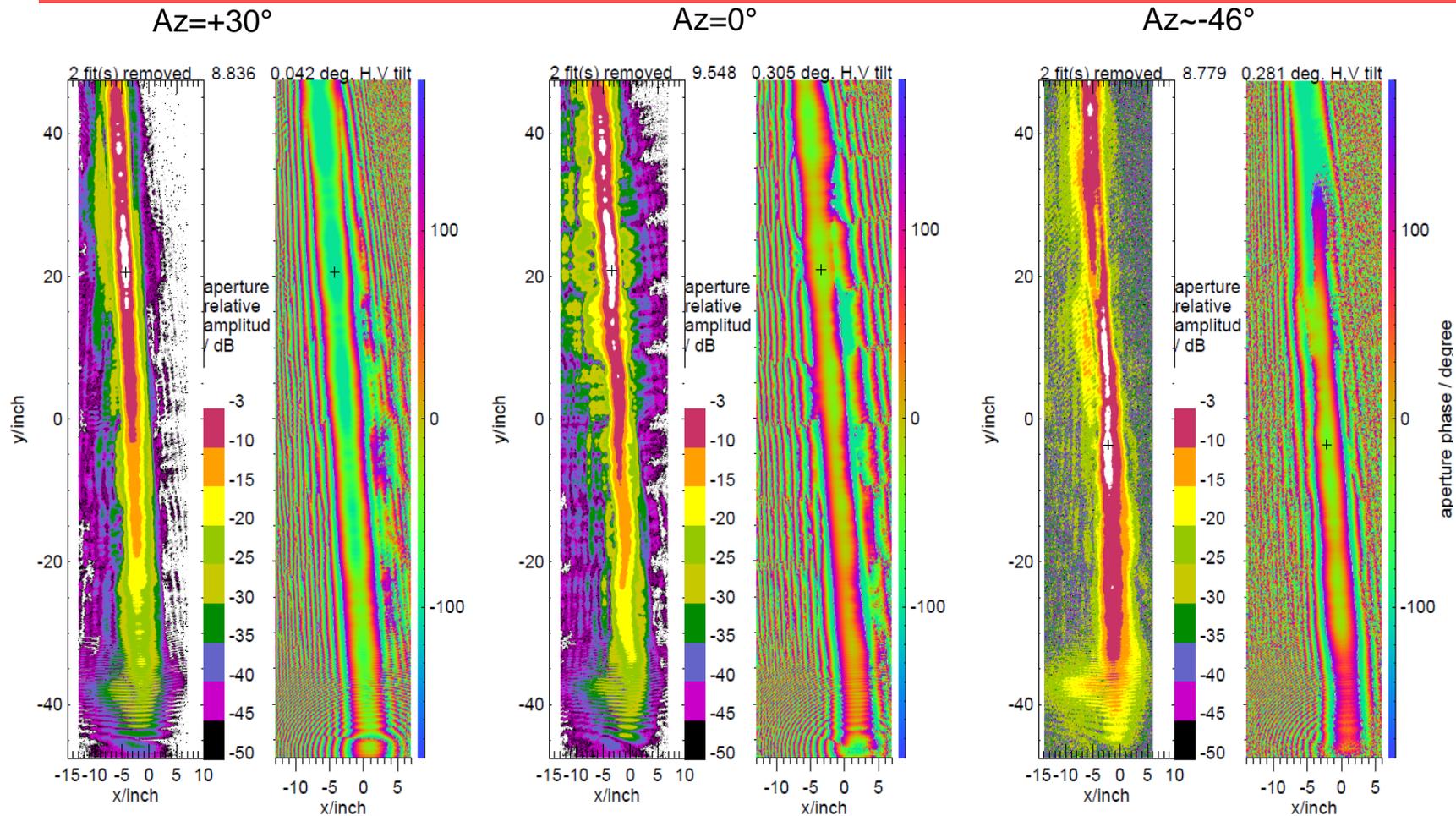
Azimuth +30

- Az ± 60 hole pattern could not be used (Primary top got too close to the scanner)
- Instead, brought LLP to Az-46 and clamped wedge in corresponding position





Az +30, 0 and ~-46 pixels (both LLP & wedge)



- similar skews of bright strips suggests misalignment of LLP rather than within antenna
- likewise planar tilts of each phase pattern
- peak NF power at much lower Y for Az~-46; still under study

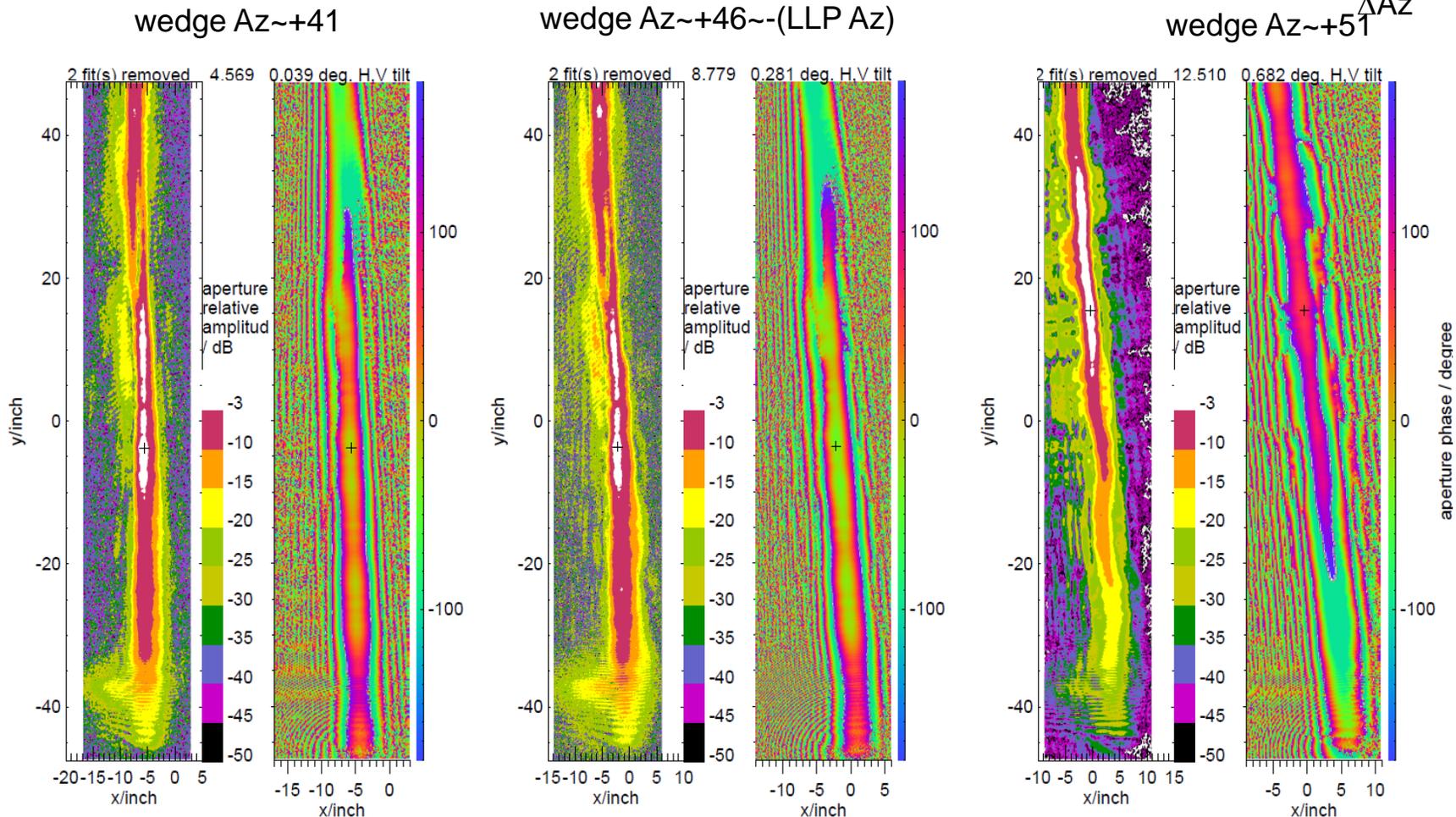


LLP Az~-46; wedge Az +51, +46 and +41



$0.35/(8\pi) \times 360^\circ \sim 5^\circ$ (CW)

wedge Az~+51 ΔAz



- skews of bright strips rotates for various wedge positions; plausible and under study
- H-tilts of phase patterns differ by slightly less than the wedge azimuth angle



Validation of Measurements by Math Model



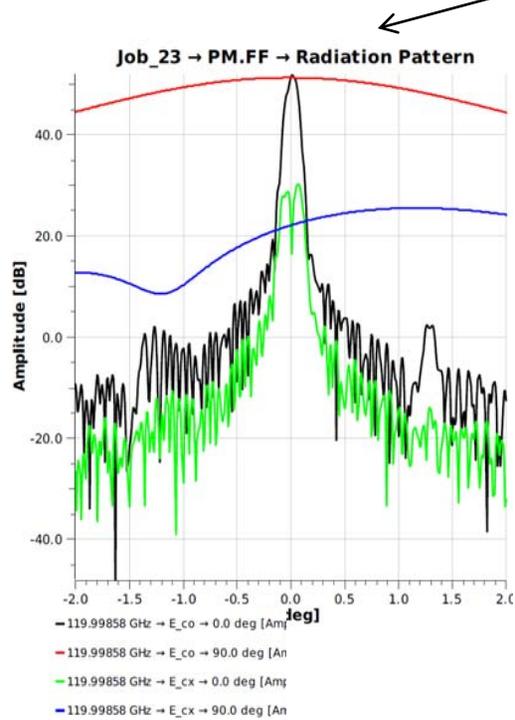
- Method:
 1. project near-field measurements to a cylinder portion using axes best-fit from the phase maps
 2. Apply a cylindrical Near-Field to Far-Field transformation developed by JPL for NSCAT [Hussein and Rahmat-Samii, 1991-3]
 3. compare to GRASP's calculations of Far fields shown in previous reviews of this IIP; confirm design intent is met.
- We are still developing this software, although all measurements are complete: grid spacings $\lambda/2$ (Az.0) or $1\lambda, 2\lambda$ (other Az.) meet the algorithm requirements
- Deem measurements complete based on comparing *Near-Field Patterns* (next slide)



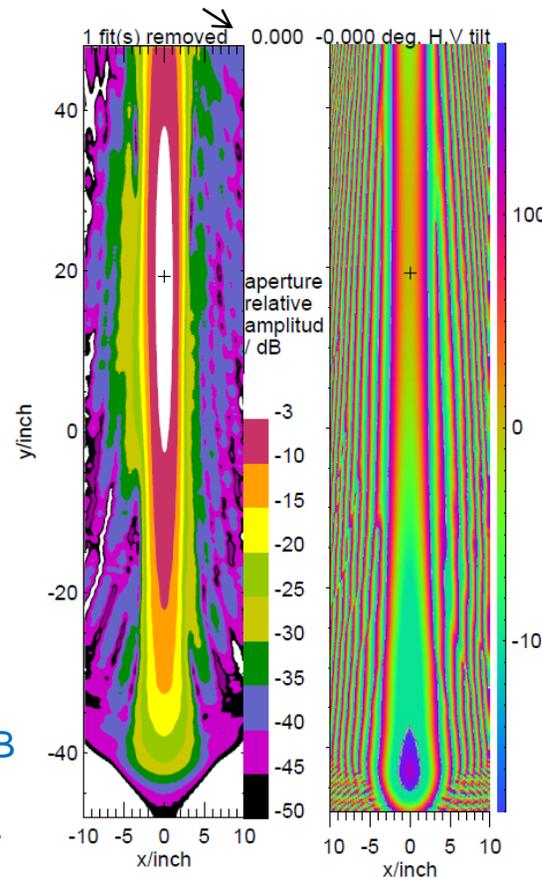
Az 0 pixel: simulation and measurement



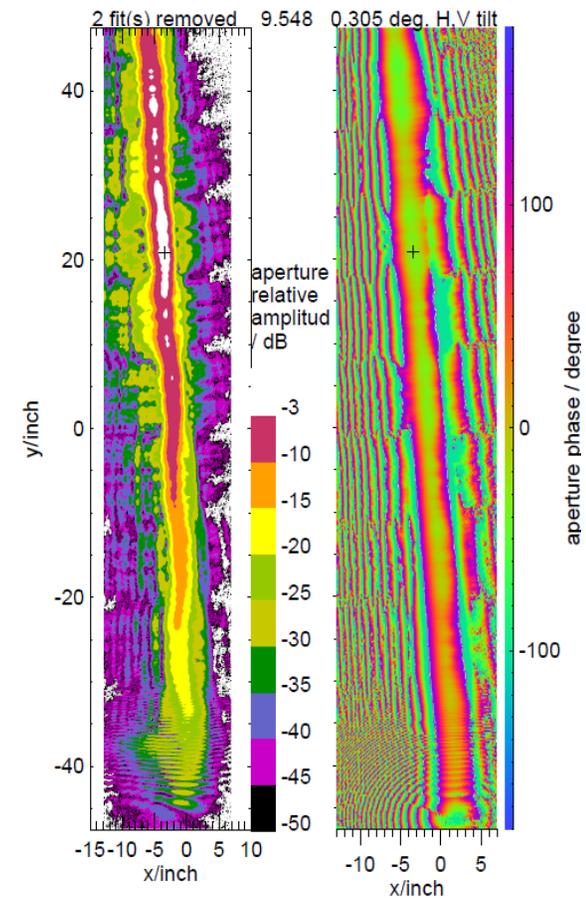
GRASP simulation: Far Field and Near Field



- X-pol isolation is 25-30dB (FF) ;25-35 dB (NF)
- measured -25 NF, once -45 dB



measured Near Field



- NF map shapes for both amplitude and phase are similar for model and measurement
 - horizontal cuts of phase map show v.similar shape (validates cylindrical phase front)
- Still studying issues of convergence (these calc.s ~16minute run time vs. a prior 9-hour run with convergence on the NF grid rather than the FF grid)

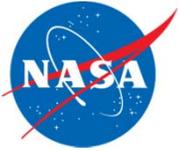


Summary and acknowledgements



- With the near field scans measured, we have completed the set of measurements for this SMLS antenna IIP
- Measurements and analysis to date support advancement to Technology Readiness Level (TRL) of 5
 - Demonstrated ability to control composite CTE to 0.05 ppm/deg.C
 - Reconciled Thermal soak, gradient tests with math models
 - Measured Near Field patterns and evaluated effect of beam pattern variations (measured and modeled, and projected for a future flight instrument) on geophysical retrievals
- Research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the National Aeronautics and Space Administration, Earth Sciences Technology Office IIP-10 program

We thank ESTO for supporting these tasks and for patience as we completed them to achieve the desired exit TRL

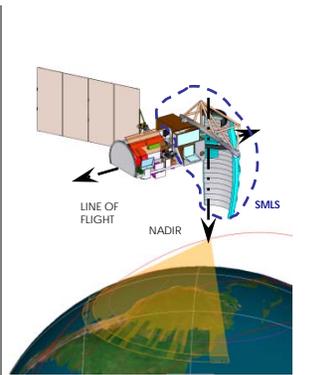


A 4 Meter 180 to 680 GHz antenna for the Scanning Microwave Limb Sounder

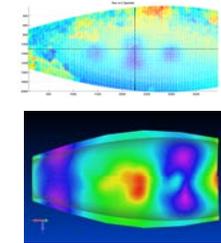
PI: Richard Cofield, JPL

Objective

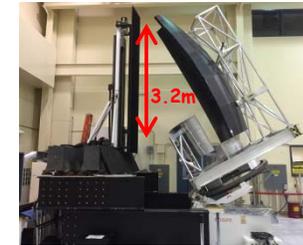
- Demonstrate fabrication and performance of the azimuth- and elevation-scanning antenna for the Scanning Microwave Limb Sounder (SMLS) on the Global Atmospheric Composition Mission (GACM).
 - Fabricate a Graphite Fiber Reinforced Composite (GFRC) reflector using a graphite mold.
 - Verify reflector performance in flight-like thermal environments using JPL's Large Aperture facility.
 - Demonstrate critical GACM requirements are met by SMLS antenna design.
 - Verify antenna performance using SMLS breadboard components.



(a) SMLS measurement Concept



(b) Primary Reflector thermal gradient tests:
above, measured;
below, structural math model



(c) Breadboard antenna in Near-Field Range for beam pattern measurements

Accomplishments

- Simulated geophysical retrievals for the SMLS antenna, including expected thermal deformations
- Fabricated a composite SMLS Primary reflector 4x1.8 m having thermal stability of 8 micron in the expected orbital thermal environment of GACM
- Tested thermal stability of an precursor SBIR and the SMLS composite Primary in a temperature-controlled facility at JPL, using a speckle interferometer to detect relative surface deformations at visible light wavelengths, with heat loads applied to the back side of the reflector. Developed a structural/optics model to correlate deformations with skin temperatures measured using IR cameras. The level of correlation was ~7%
- Fabricated and aligned breadboard antenna combining composite Primary with aluminum reflectors and structure.
- Measured near-field patterns at 120 GHz of 3 Azimuth pixels (+30, 0 and -45°) within the $\pm 65^\circ$ design range of SMLS and showed good comparison with a Physical Optics model

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TRL_{in}=3

TRL_{out}=5