Holographic Measurements and Performance of the NASA-JPL-DSN new 34-m BWG Antenna

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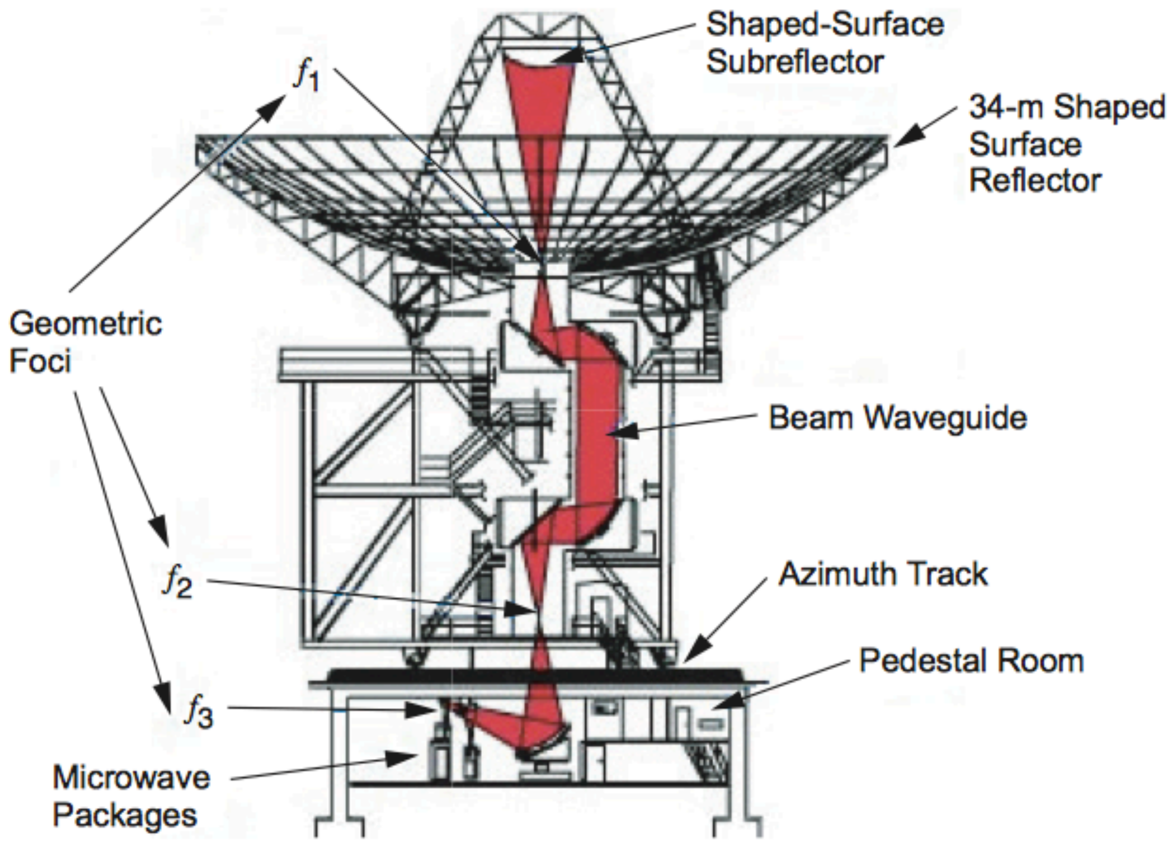
NRAO Metrology and Control of Large Telescopes

http://descanso.jpl.nasa.gov/monograph/series10/08_Reid_chapt+8.pdf

DSN 34-meter Beamwaveguide (BWG) Antenna

http://descanso.jpl.nasa.gov/monograph/series10/08_Reid_chapt+8.pdf

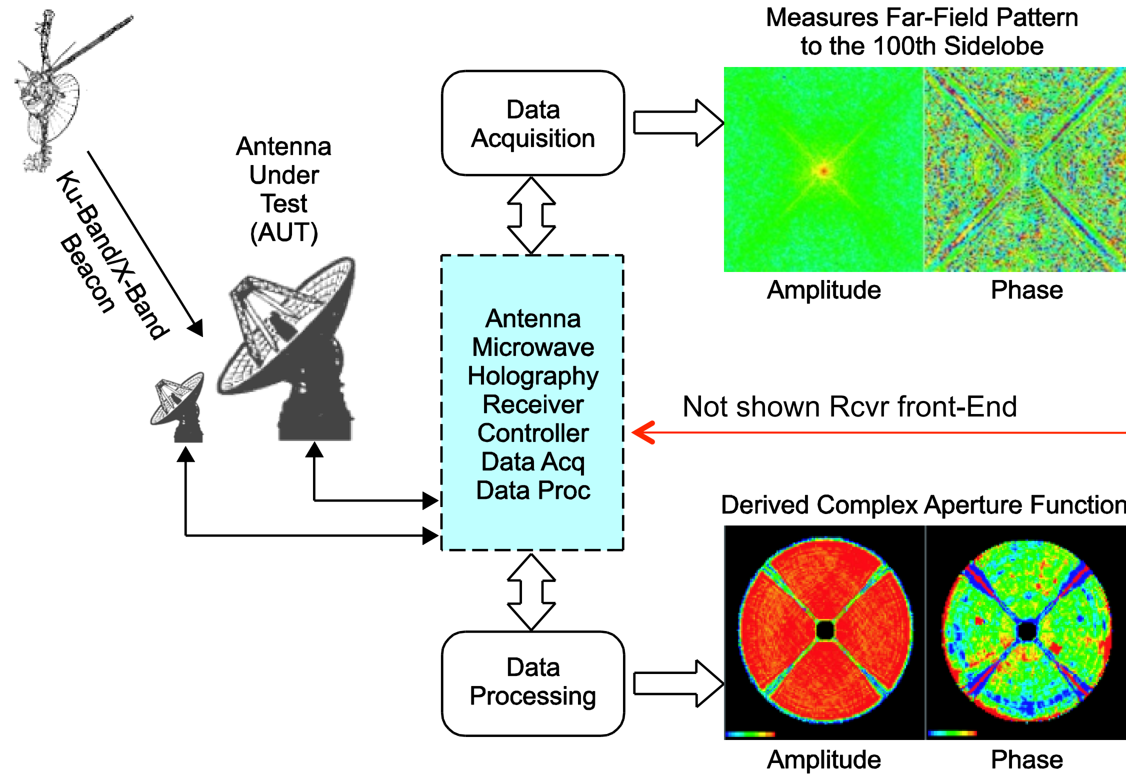


Antenna Holography Measurement Group (AHMG)

- **General physical description: 2.8-m reference antenna, Ku-Band feeds, LNA's, down converters, IF amplifiers, PLL, back-end receiver, computer control for DAQ and DAP, H/W and S/W**

- **The MAHST can service any of the DSN antennas:**
  - **Receiver design enables locking and tracking of Ku-Band satellite CW beacon in the 10.6-12.6-Ghz frequency band**
  - **Antenna surface error maps**
  - **Antenna aperture amplitude illumination maps**
  - **Panel setting screw adjustment listing output**
  - **Predicted antenna surface rms after panel setting**
  - **Subreflector position correction**
  - **Antenna gravity deformation characteristics and analysis**
  - **Servo Performance Characterization**
  - **Constructed feed phase function**

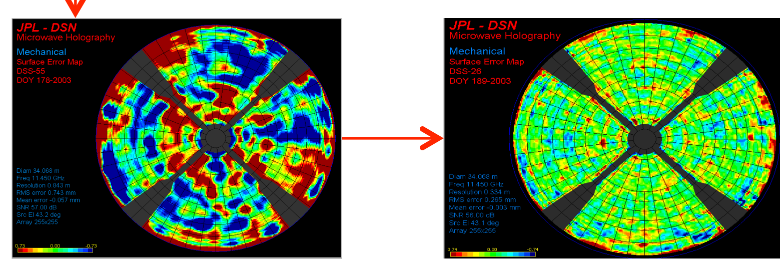
NRAO Metrology and Control of Large Telescopes



Back-End Receiver

Major components from top to bottom of back-end receiver:

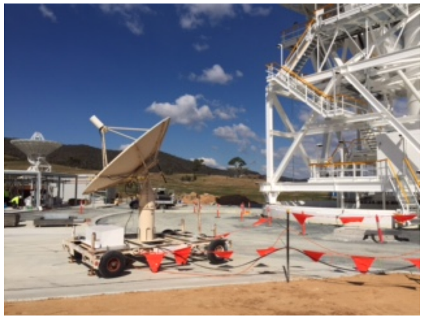
- Spectrum analyzer ESA-E4401B
- 2-Channels HP8530A Microwave receiver
- HP117113A Attenuator/ Switch driver
- computer and pull-out monitor
- Frequency synthesizer HP-ESG-E4423B
- 2-Channels IF Receiver & PLL
- Power supply



DSS-55/ Before Holography

DSS-55/ After Holography =+5-dB

Installing the AHMG Front-End at DSS-36 F1



Installing the AHMG Front-End at DSS-35 F3

DSS-36: Summary of final Holography RMS (mm) Results

Mirror	QA RMS	RMS Spec.	Max. Deviation	Min. Deviation
SR	0.069	0.127	0.262	-0.125
M1	0.041	0.100	0.087	-0.160
M2	0.072	0.100	0.266	-0.186
M3	0.080	0.100	0.222	-0.254
M4	0.048	0.100	0.144	-0.126
M5	0.089	0.100	0.260	-0.264
M7	0.016	0.100	0.045	-0.053
RSS (BWG - SR)	0.154	Predicted RSS of BWG mirrors error excluding the Subreflector		
RSS (BWG+SR)	0.169	Predicted RSS of BWG mirrors error including the Subreflector		
RSS (Main+BWG +SR)	0.196	Predicted Ultimate surface measured form F3		
RSS (Main+SR)	0.121	Predicted Ultimate surface measured form F1		
Main + SR F1	0.266	As set by photogrammetry & measured by Holography		
Main + SR F1	0.192	As set by & measured by Holography		
F3 Measured	0.251	From Holography Night-Time		

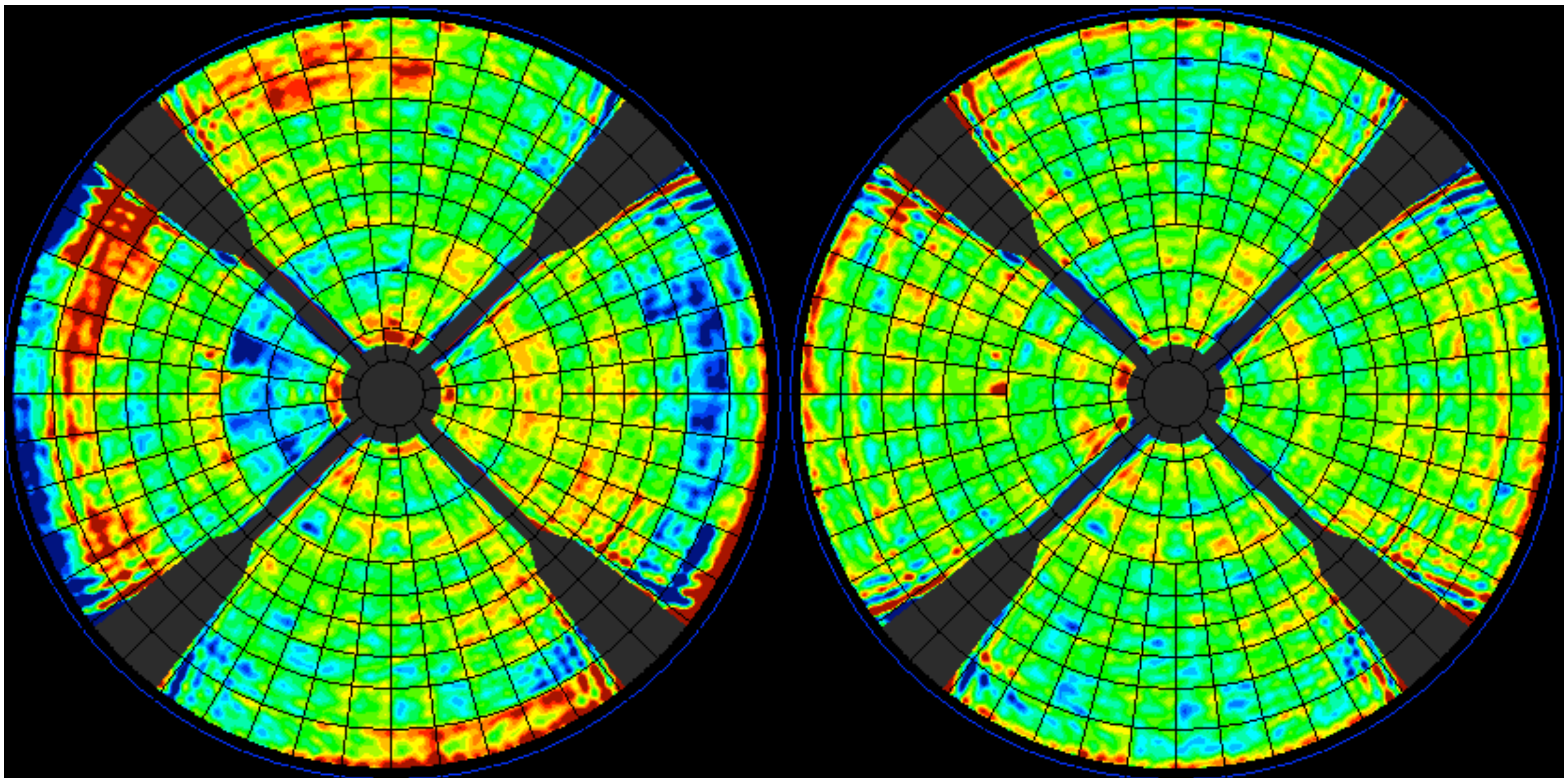
DSS-36 Predictions & Results Prior & After Expedition
Photogrammetry predicted at 0.240-mm versus actual 0.266-mm

DSS	Case	Hi-Res (mm)	Med-Res (mm)	Low-Res (mm)	41x41 Holo (mm)
After Photogrammetry & Before Holography Panel Settings					
35	Holo+SR	**0.261**[2]	0.209	0.179	0.194
35	Holo-SR	**0.243**	0.187	0.152	**0.170**[1]
35	Holo-SR	100%	77%	62.5%	70%
DSS-36 Predictions Versus As Found RMS					
36	Holo -SR	**0.229**[2]	Computed / Predicted		**0.160**[1]
36	Holo+SR	**0.240**[3]	Computed / Predicted		0.160
36	Holo+SR	**0.266**	Set by Photo-G & measured by Holography		
36	Holo+SR	**0.192**	Set & measured by Holography		

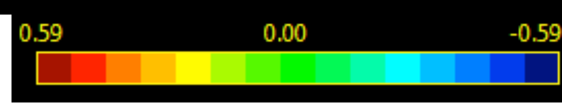
(1): **Predicted Photogrammetry rms value (by holography) based on 1716 samples near panel adjusters, equivalent to 41 X 41 holography array**

(2/3): **SR rms: 0.093-mm for DSS-35 and 0.069-mm for DSS-36**

DSS-36 F1 Surface Before / After Holography
Gain improvement due to surface alignment at Ka-Band = 0.3-dB



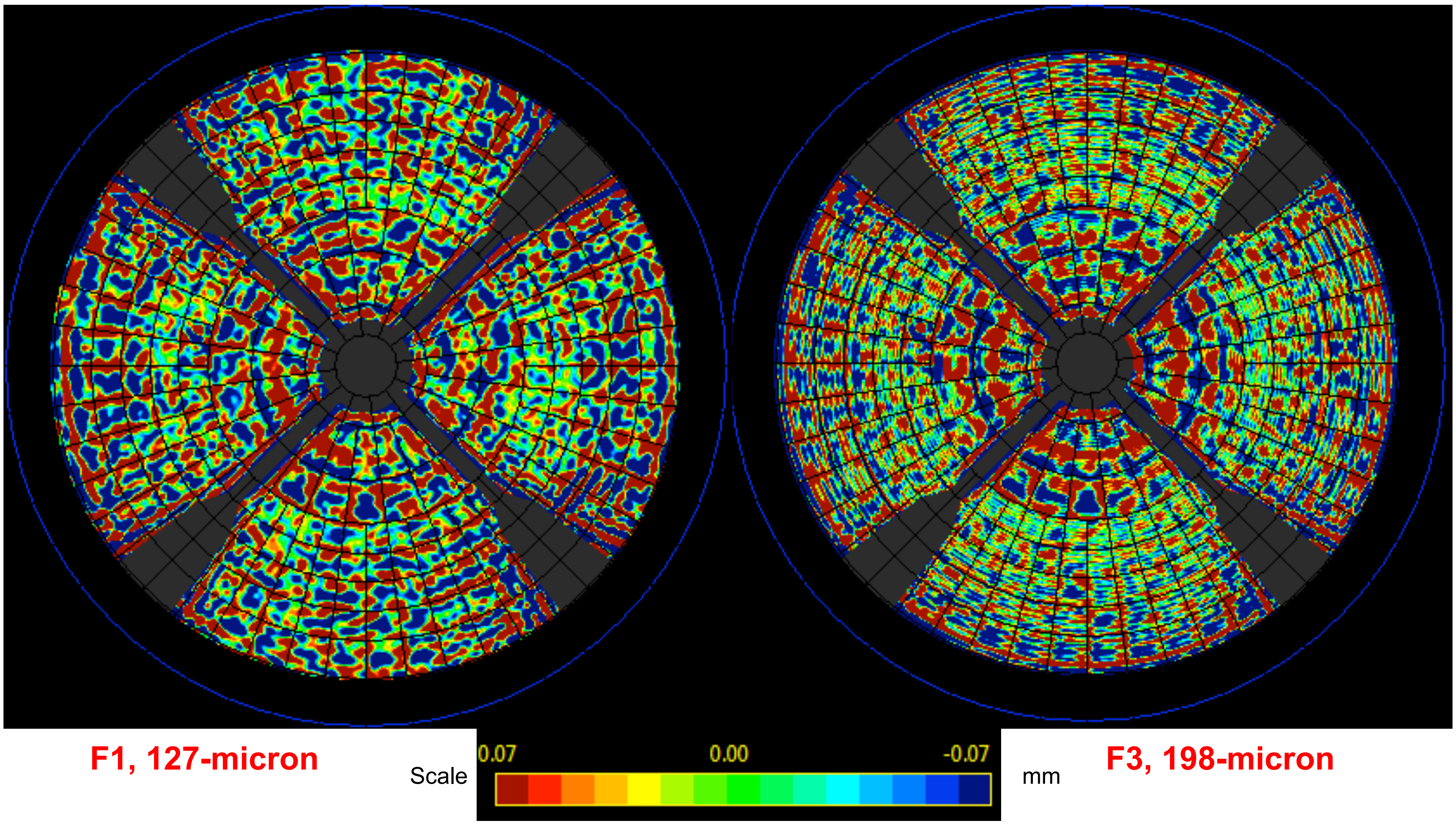
Before Holography
rms = 0.266-mm



Scale mm

After Holography Panel Settings
rms = 0.192-mm

Ultimate RMS Surface: 0.127-mm F1 / 0.198-mm F3, Revealing Individual panels imperfections, 10-micron resolution



Summary Results for DSS-36

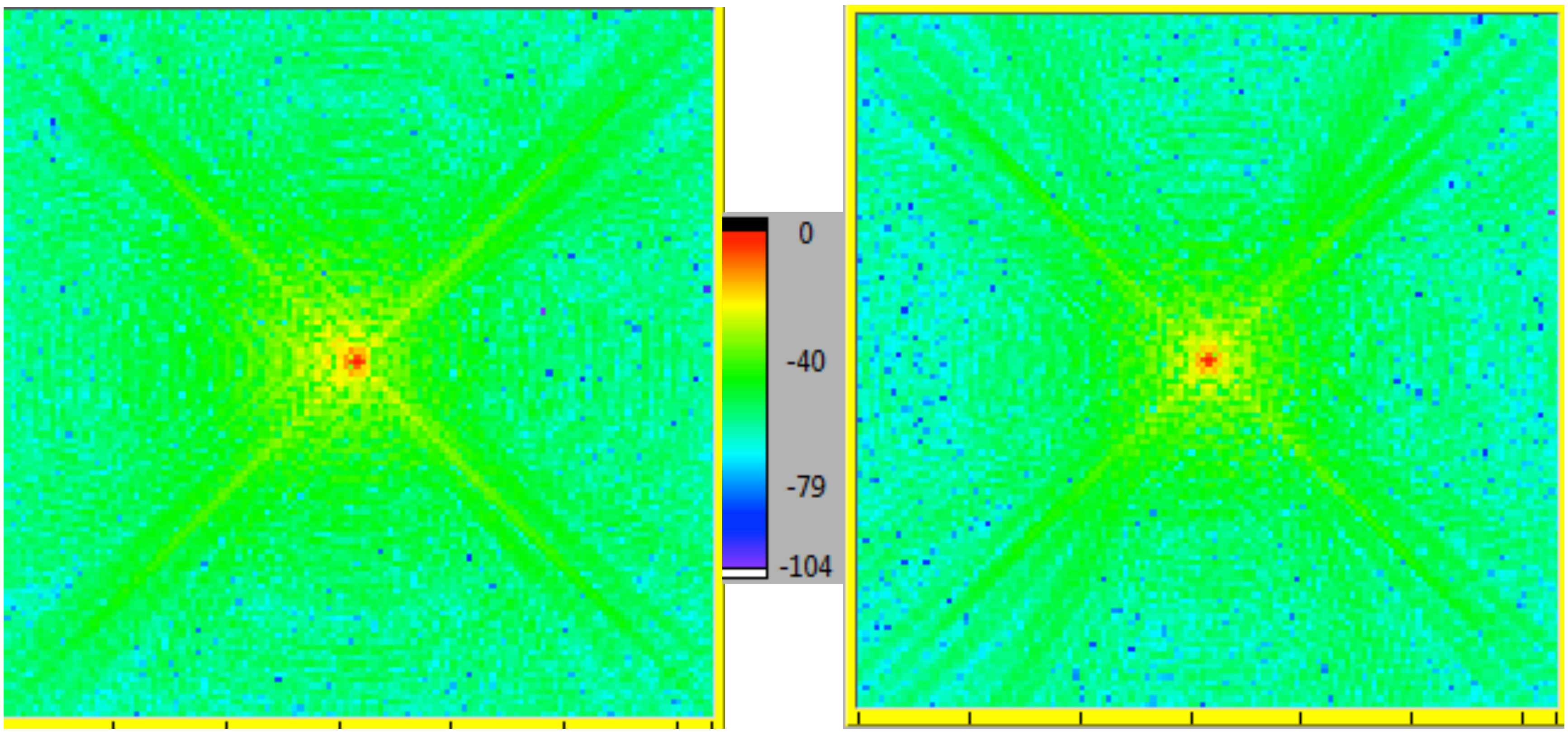
Initial antenna normal rms as set by photogrammetry, (high-resolution, 33-cm) for the 95% dish diameter was 0.266-mm. The 97% of the dish diameter rms was 0.332-mm

Final antenna normal rms post holography, (high-resolution, 33-cm) for the 95% dish Diameter is 0.192-mm. The 97% of the dish diameter rms is 0.203-mm

This improvement in panel alignment (alone) corresponds to 4% increase in efficiency at Ka-Band, or +0.27-dB, and enabling antenna aperture efficiency at Ka-Band of 66%. The highest achieved to date in the DSN.

More than 200 panels were adjusted
Zero-set the azimuth encoder
Confirmed the antenna uniform aperture amplitude illumination, and hence its correct dual-shaped cassegrain design
Aligned subreflector
Noticed additional diffraction pattern in the data due to the quad noise shields

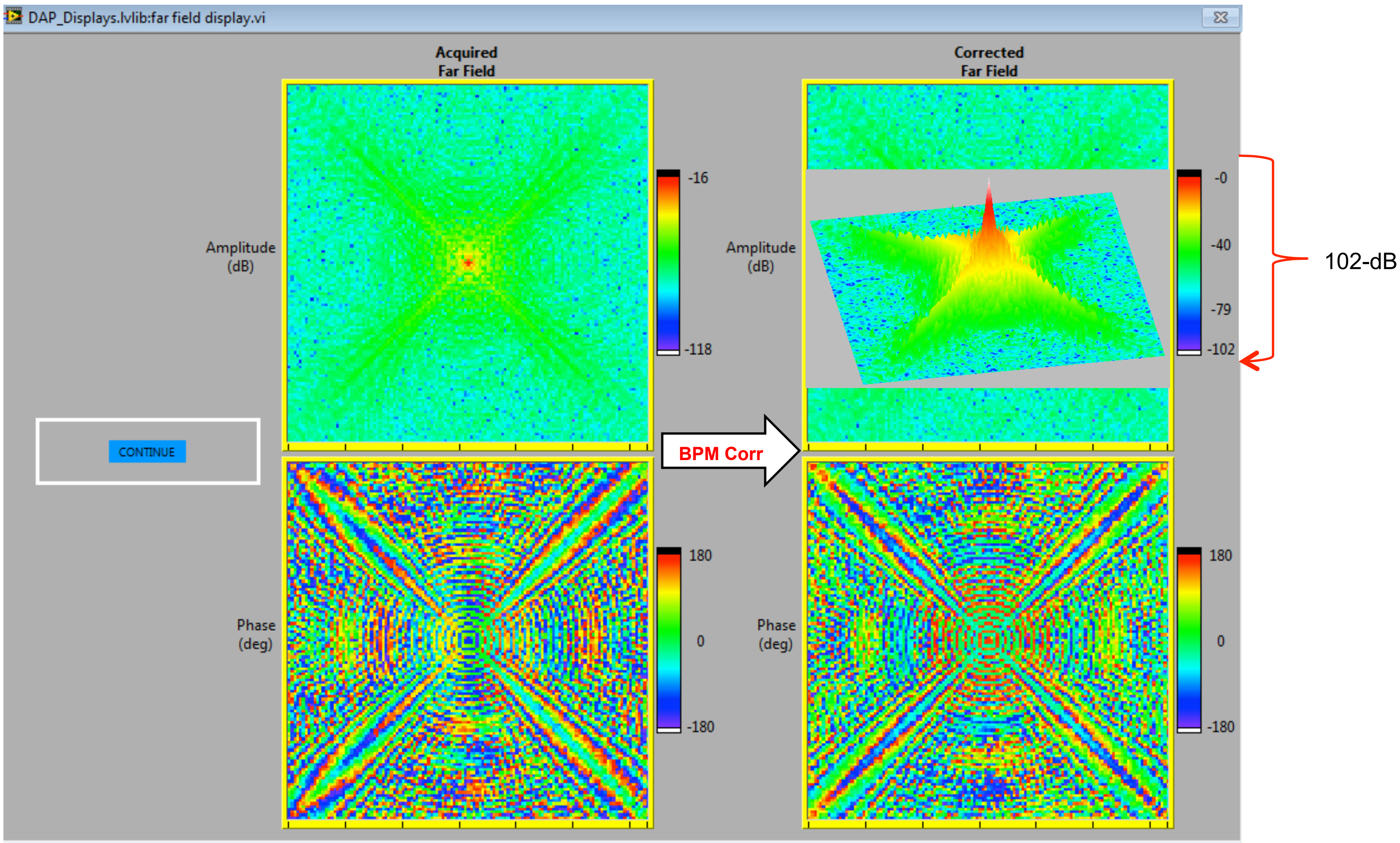
DSS-36 Far-Field Pattern before / after SR Tilt and X –axis Alignment



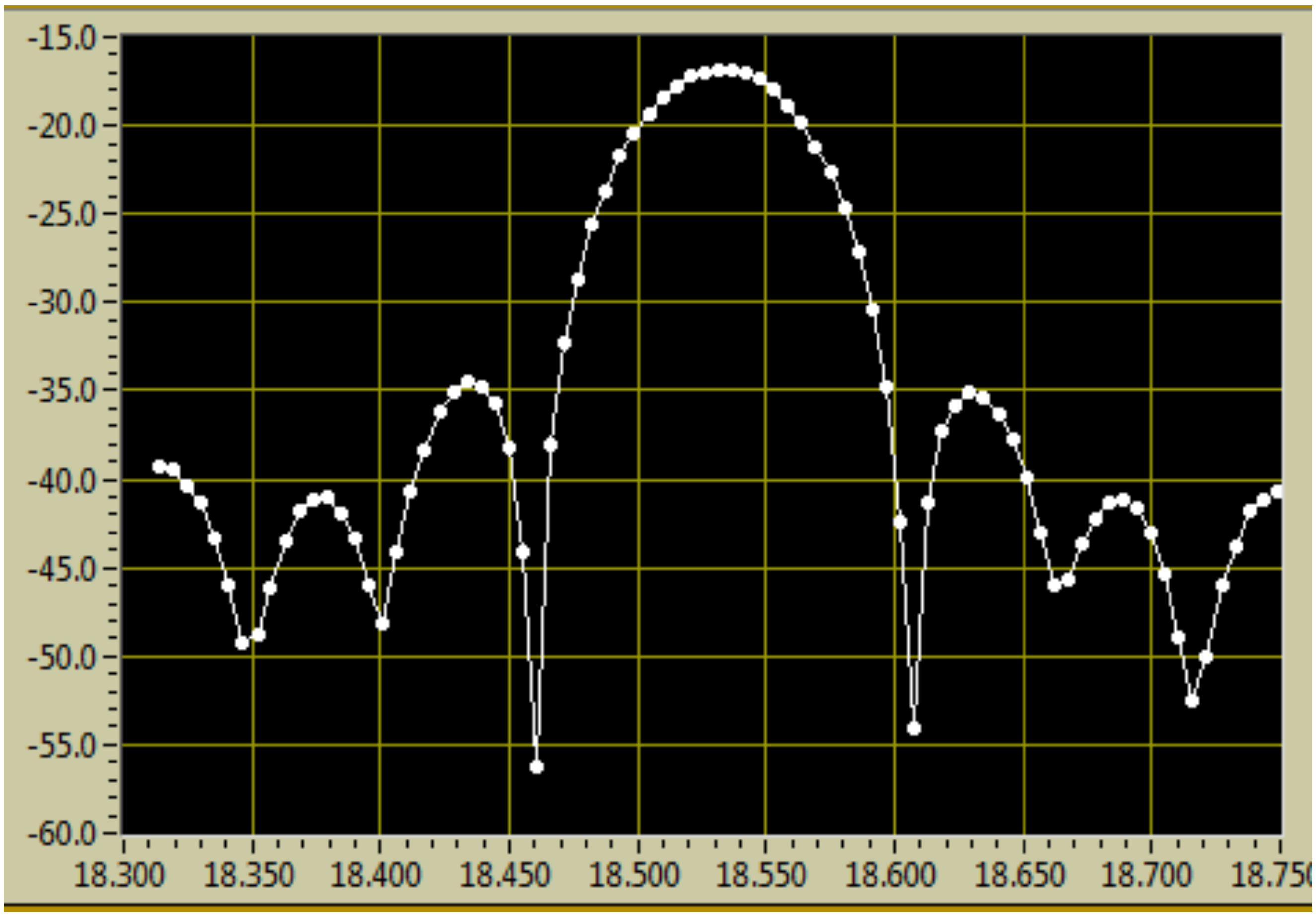
DSS-36 Far-Field Pattern after Subreflector alignment In the Z and Y axes but not X-axis. Showing the far-field Pattern skew to the left in the plot above

DSS-36 Far-Field Pattern after Subreflector alignment In the Z, Y,and X axes. Showing the far-field Pattern symmetry

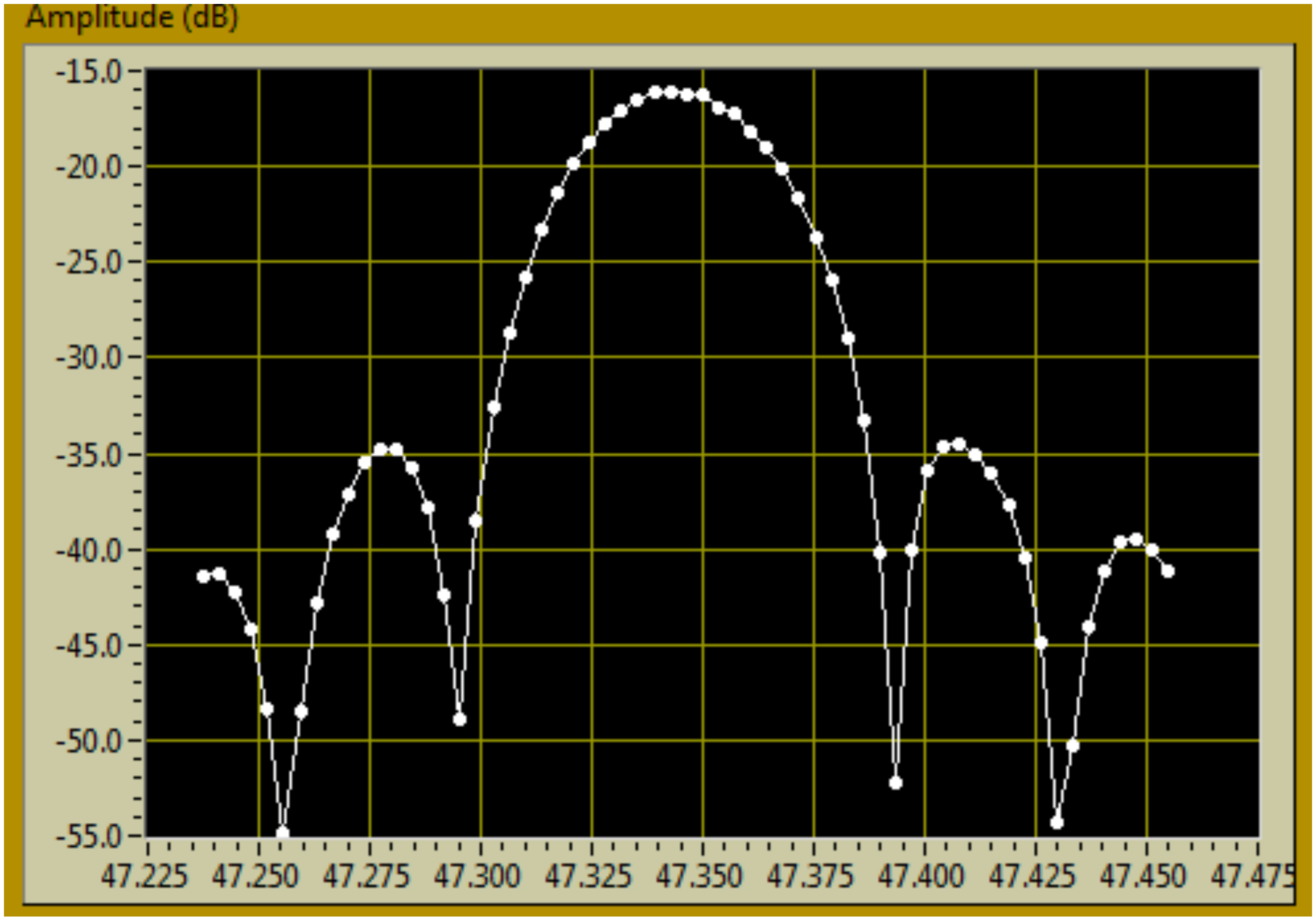
DSS-35 Complex (Amplitude and Phase) Far-Field 2-D Pattern Shown with 102-dB Dynamic Range (AHMG) at Ku-Band (12.75-GHz) exhibiting well behave symmetric pattern



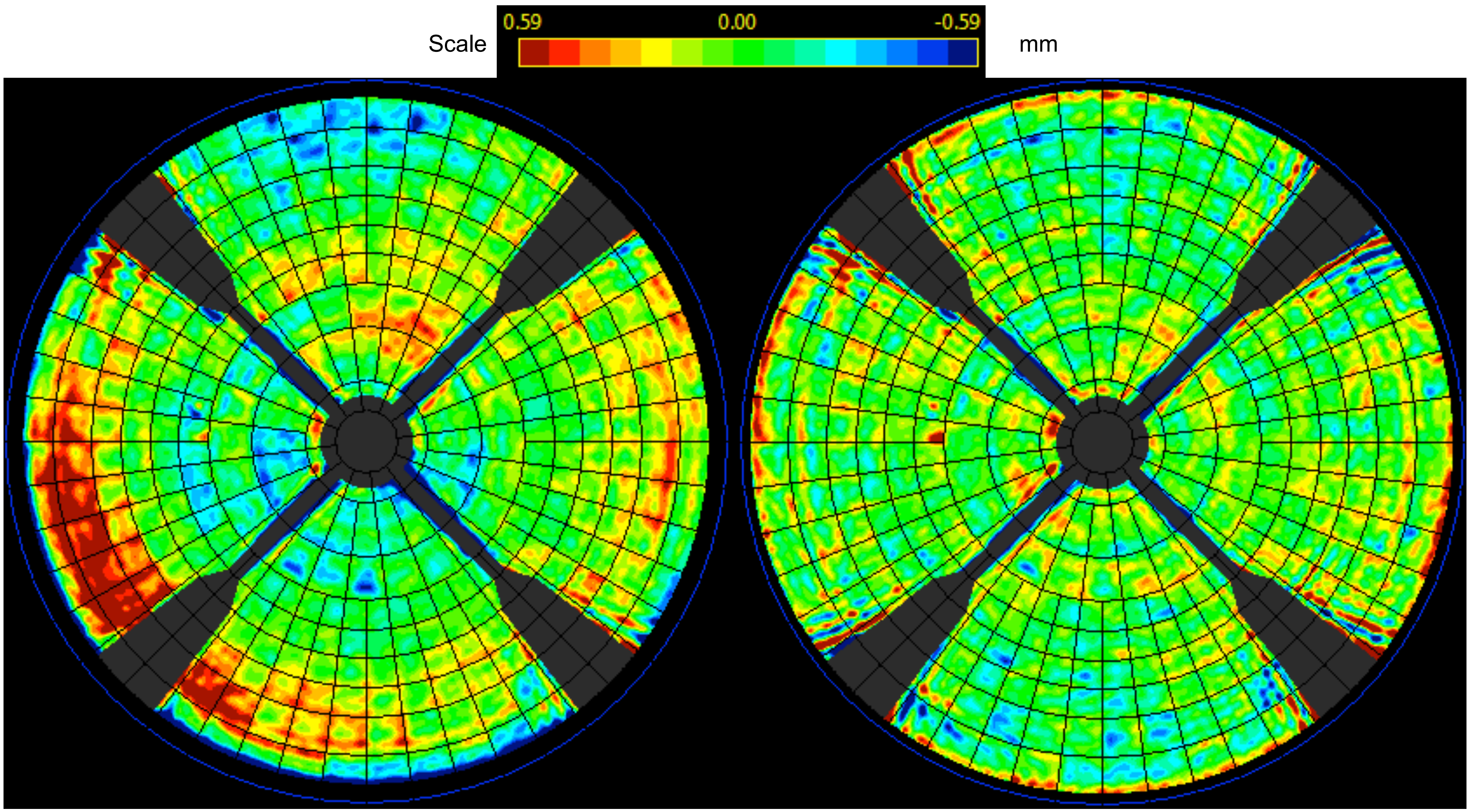
DSS-35 Far-Field Pattern Azimuth Cut at Ku-Band (12.75-GHz) with Even and 18-dB Down Sidelobes, Indicating excellent Antenna Performance: Dish Surface and Subreflector Alignment from F1 Focus



DSS-35 Far-Field Pattern Elevation Cut at Ku-Band (12-GHz) with Even Sidelobes and 18-dB Down Confirming excellent Antenna Performance: Dish Surface and Subreflector Alignment from F1 Focus



DSS-36 F1 versus F3 Holography

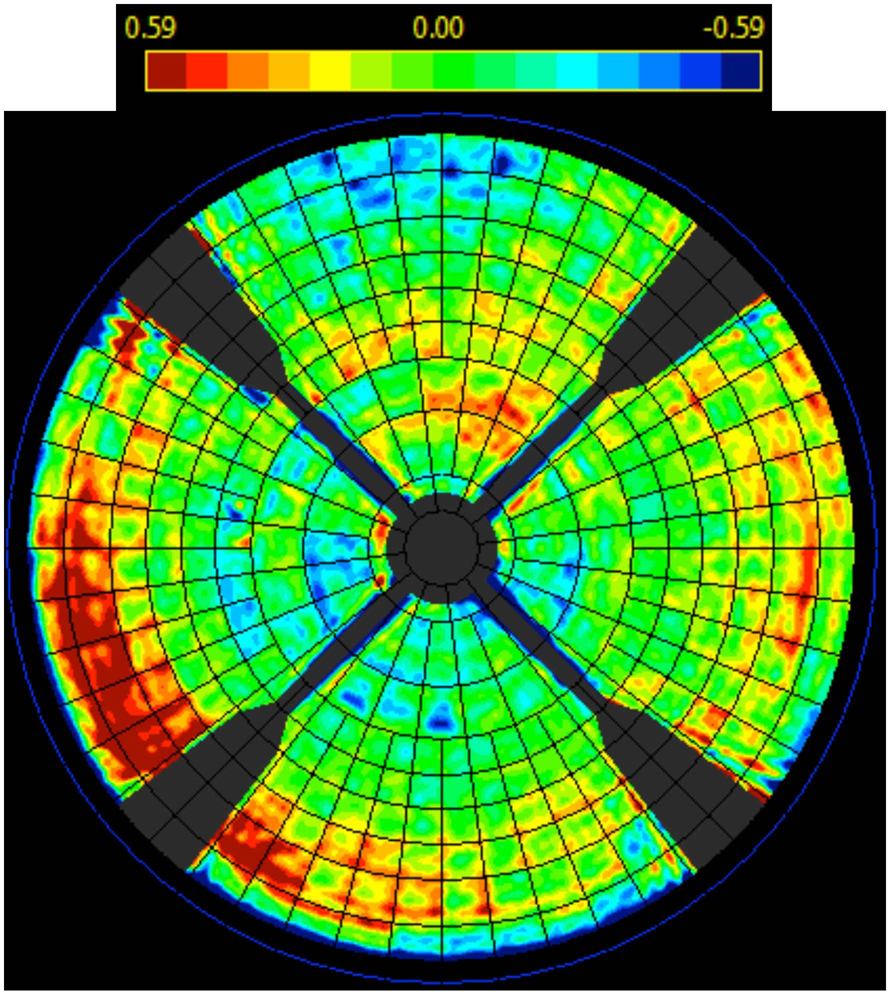


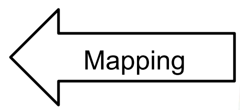
F3 Holography 0.251-mm rms to the 95% which is RSS diff = 0.259-mm (97-micron per mirror Ave)

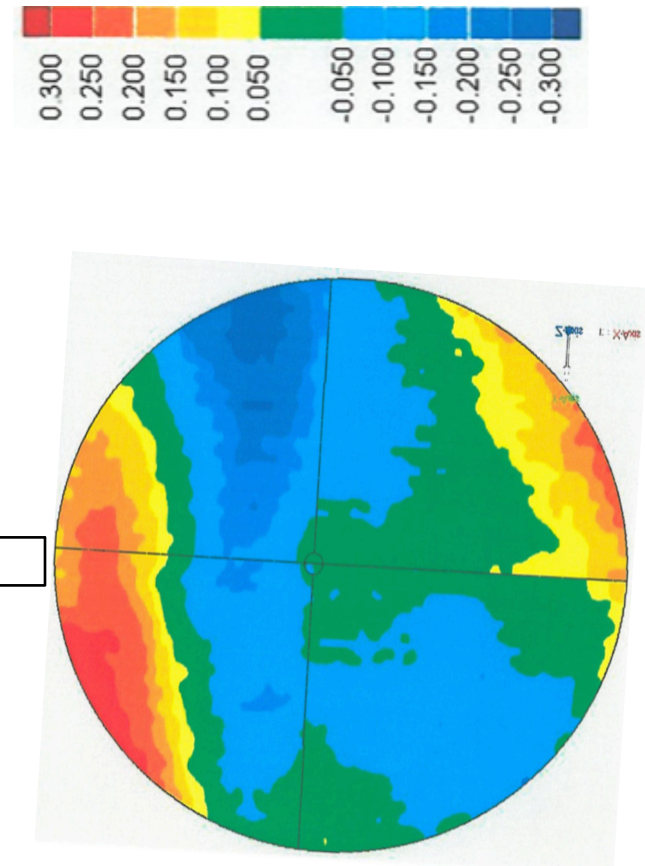
36-16106-0737 / F3

After Holography Panel Settings The rms for the F3 illumination diameter (95%) is **192-micron**

Deformation Signatures from F3 Correlation with M5 Deviations







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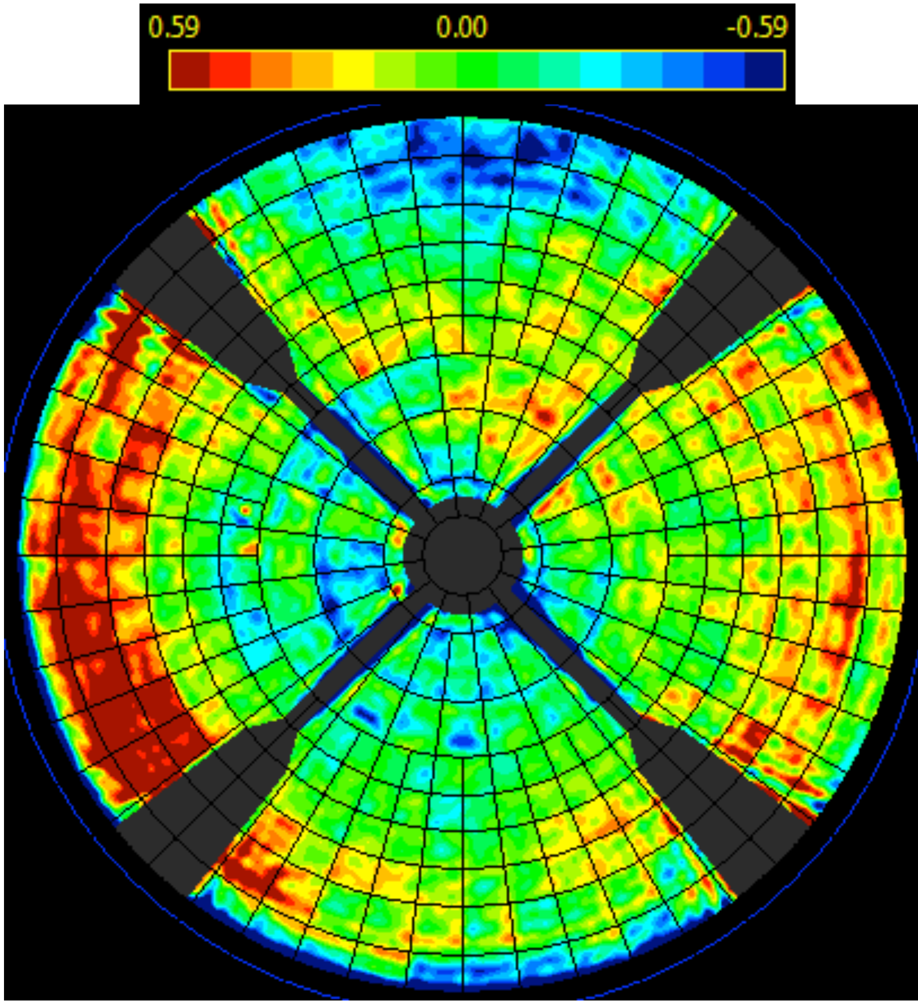
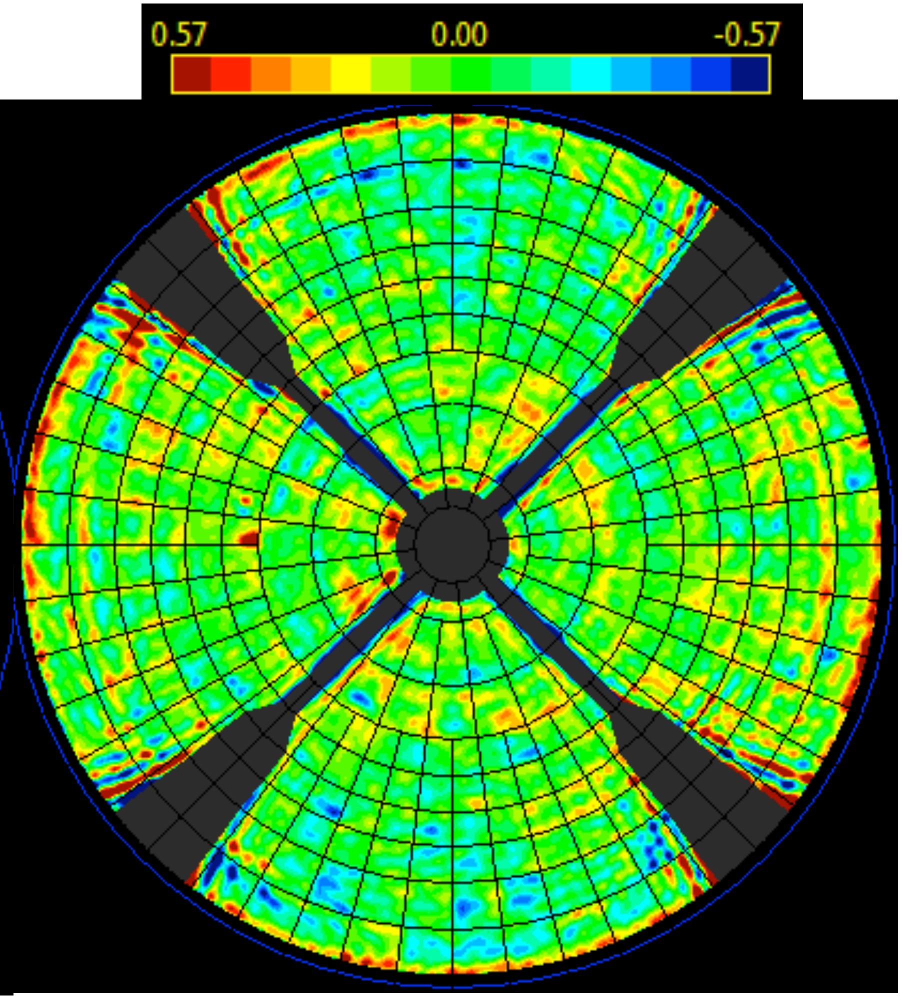


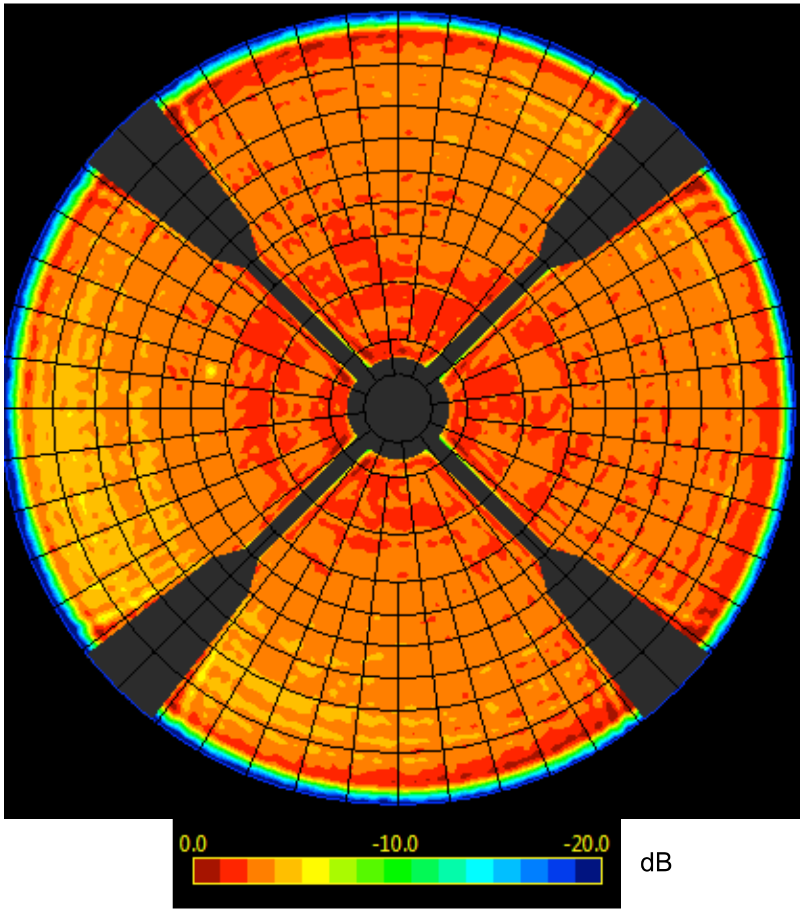
F3 Holography High-Resolution Day-time
36-16123-0035: Rms = 0.288-mm

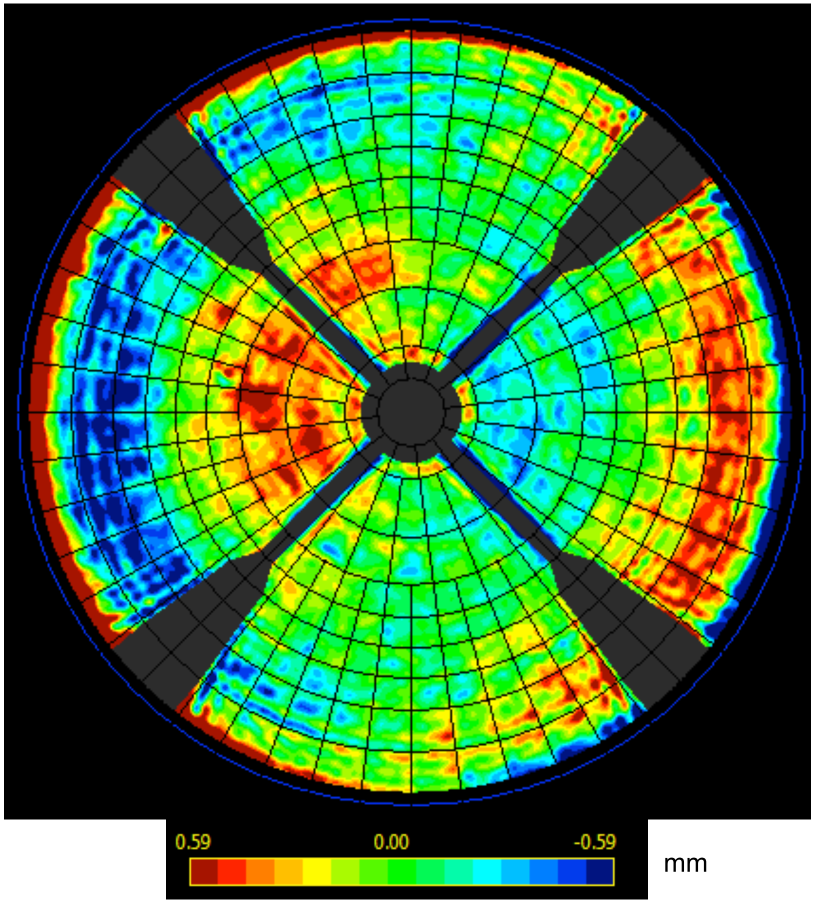


After Holography Panel Settings rms = 0.203-mm
The rms for the F3 illumination diameter (95%) is **192-micron**

Dish as found F1 high-resolution

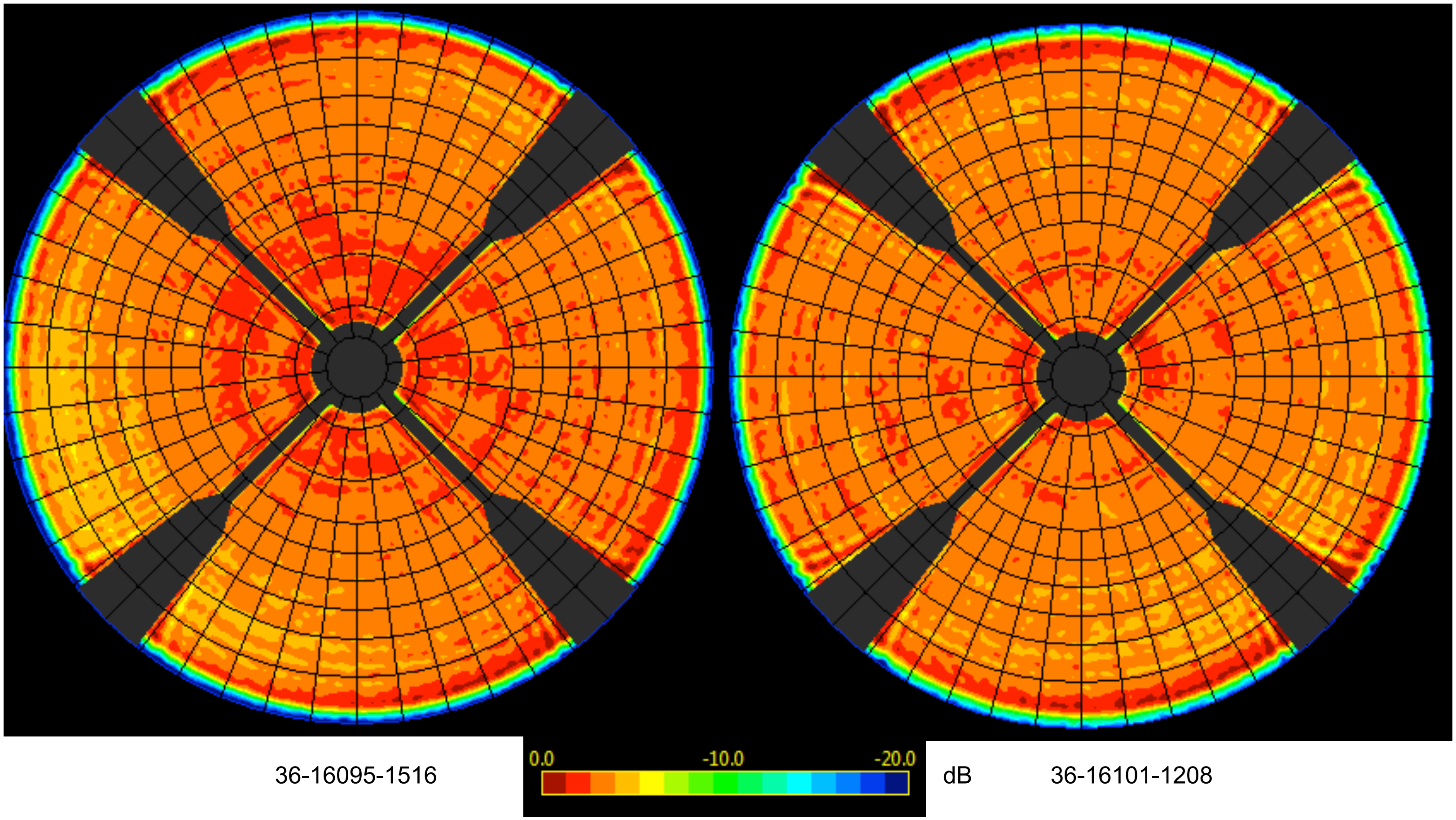
Showing energy distribution across the dish skew to the right. This will later be confirmed as a result of a subreflector tilt and translation errors.





After Subreflector Tilt and Translation Corrections

Noticed the improvement in the symmetry of the energy distribution across the antenna main dish

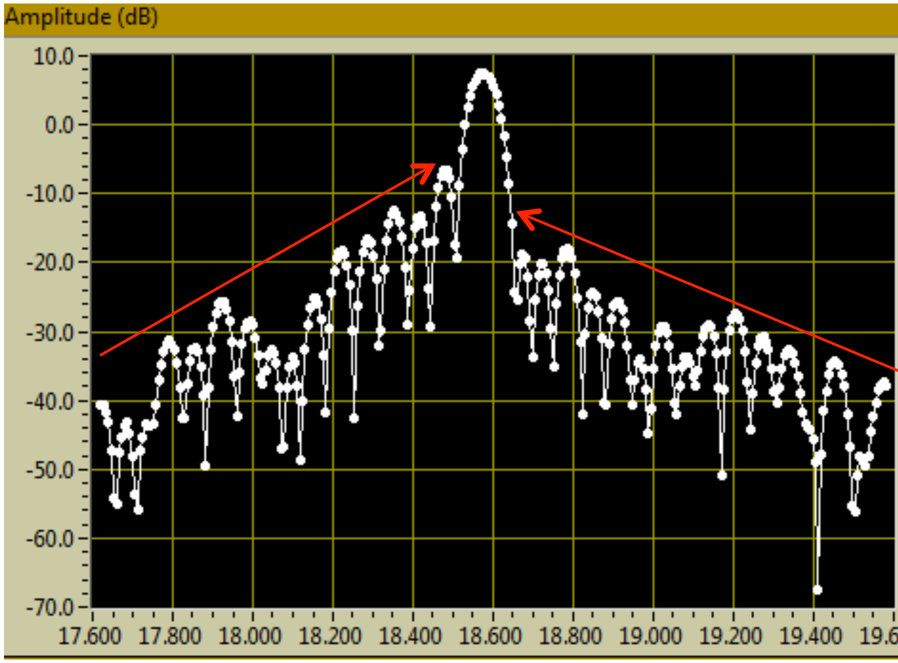


36-16095-1516

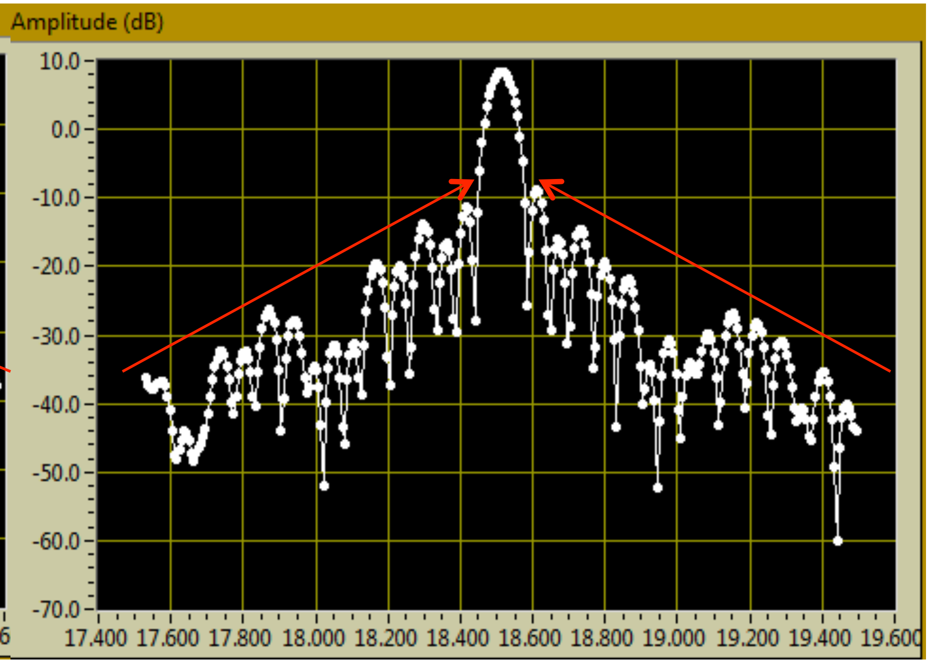
36-16101-1208

Azimuth Far-Field Pattern Before / After Subreflector Tilt and Translation Corrections via Holography

Noticed a dramatic improvement in the Far-Field Amplitude Sidelobes formation

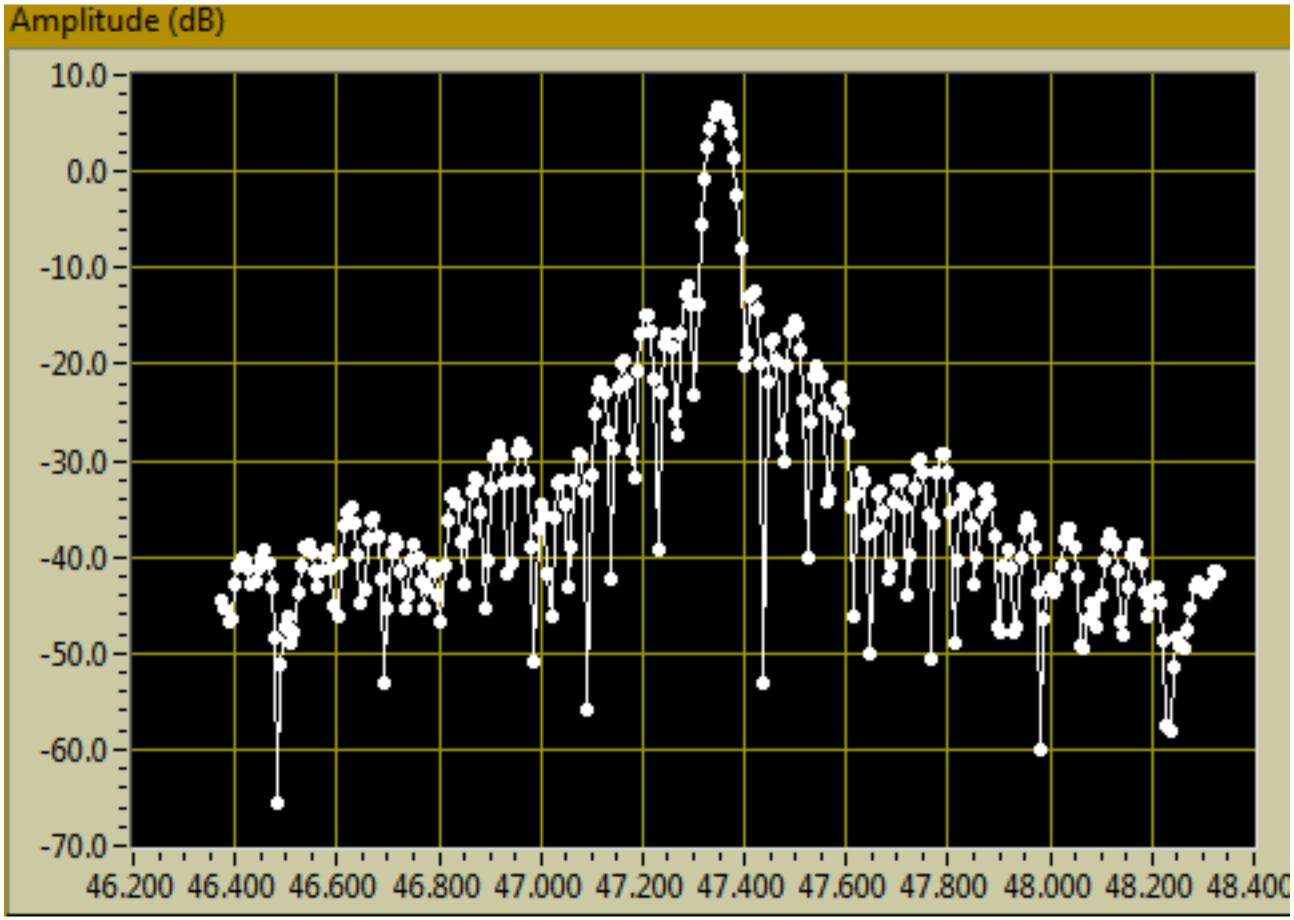


Az FF Before SR Tilt and translation Corrections



Az FF AFter SR Tilt and translation Corrections

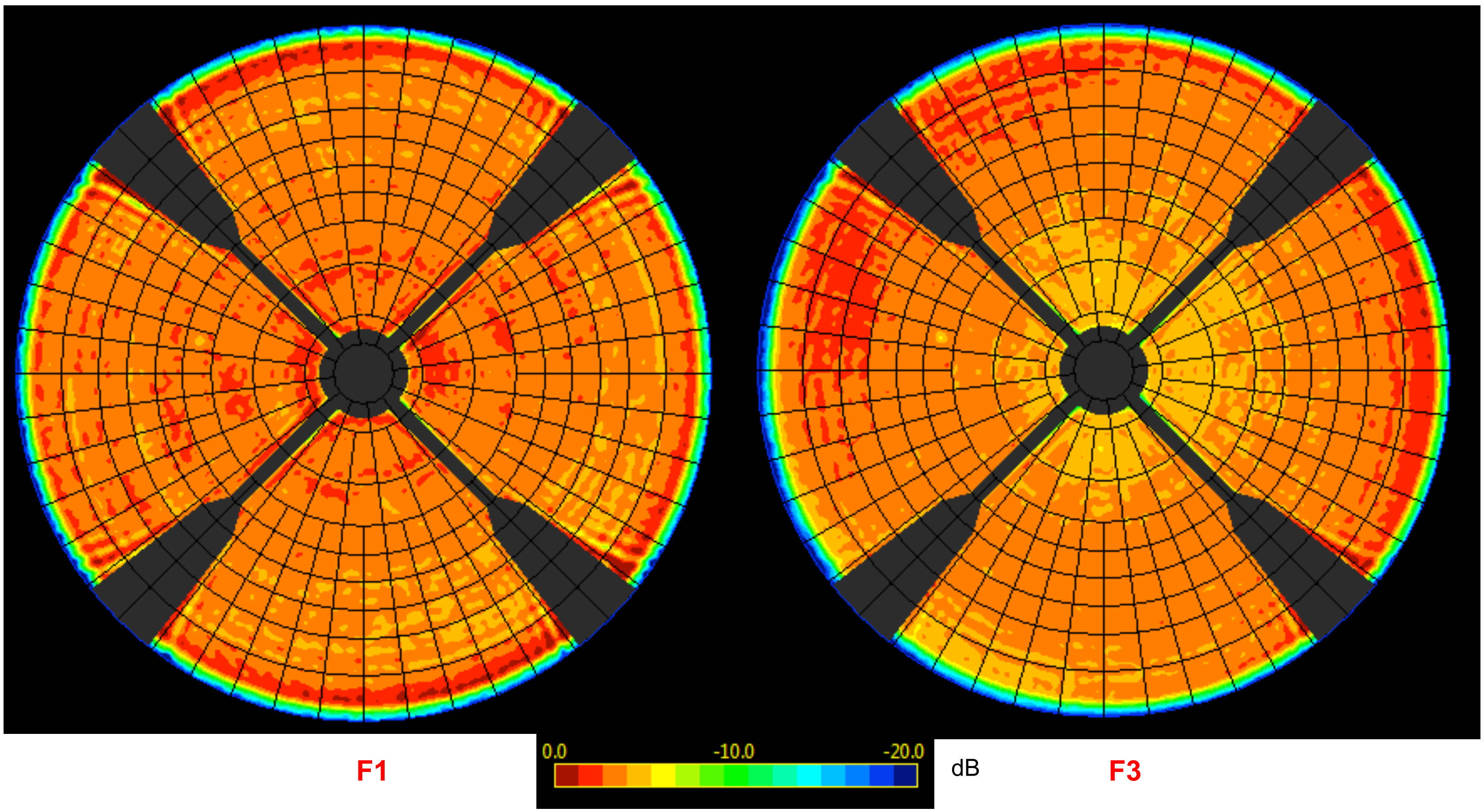
Elevation Far-Field Pattern After Subreflector Translation Correction via Holography



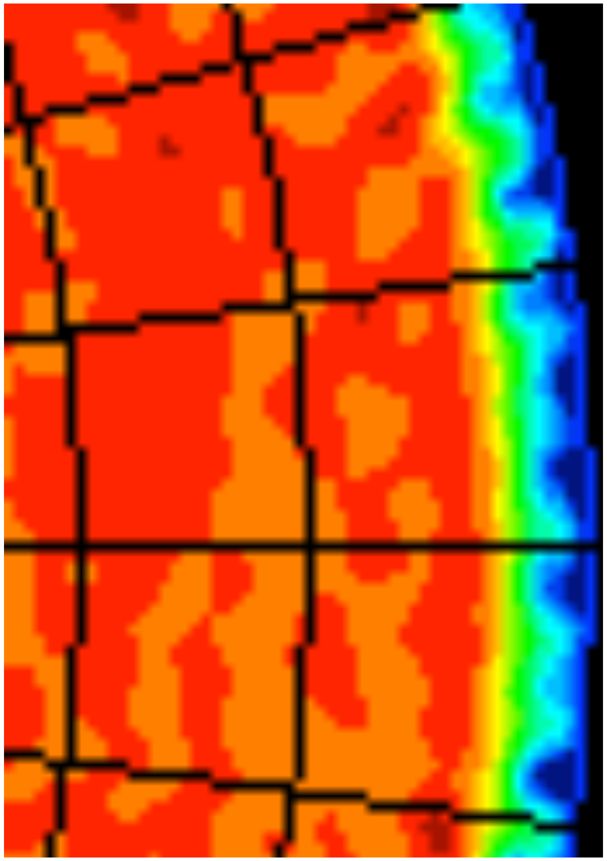
DOY 104, 2016 Final Elevation Wide Angle (4-deg) Cut

F1 versus F3 Aperture Illumination Function

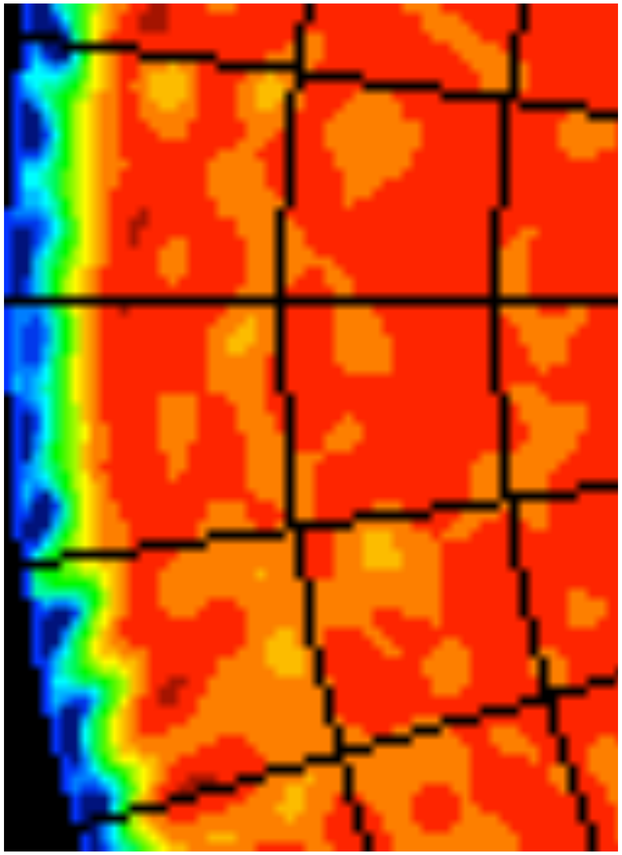
Slight Shift in Energy Distribution noticed at F3



DSS-35 Antenna Aperture Amplitude Illumination Comparison between F1 Right and F3 Left



F3 Day Time DOY 091 Slightly Under Illuminated



F1 Night Time DOY 077

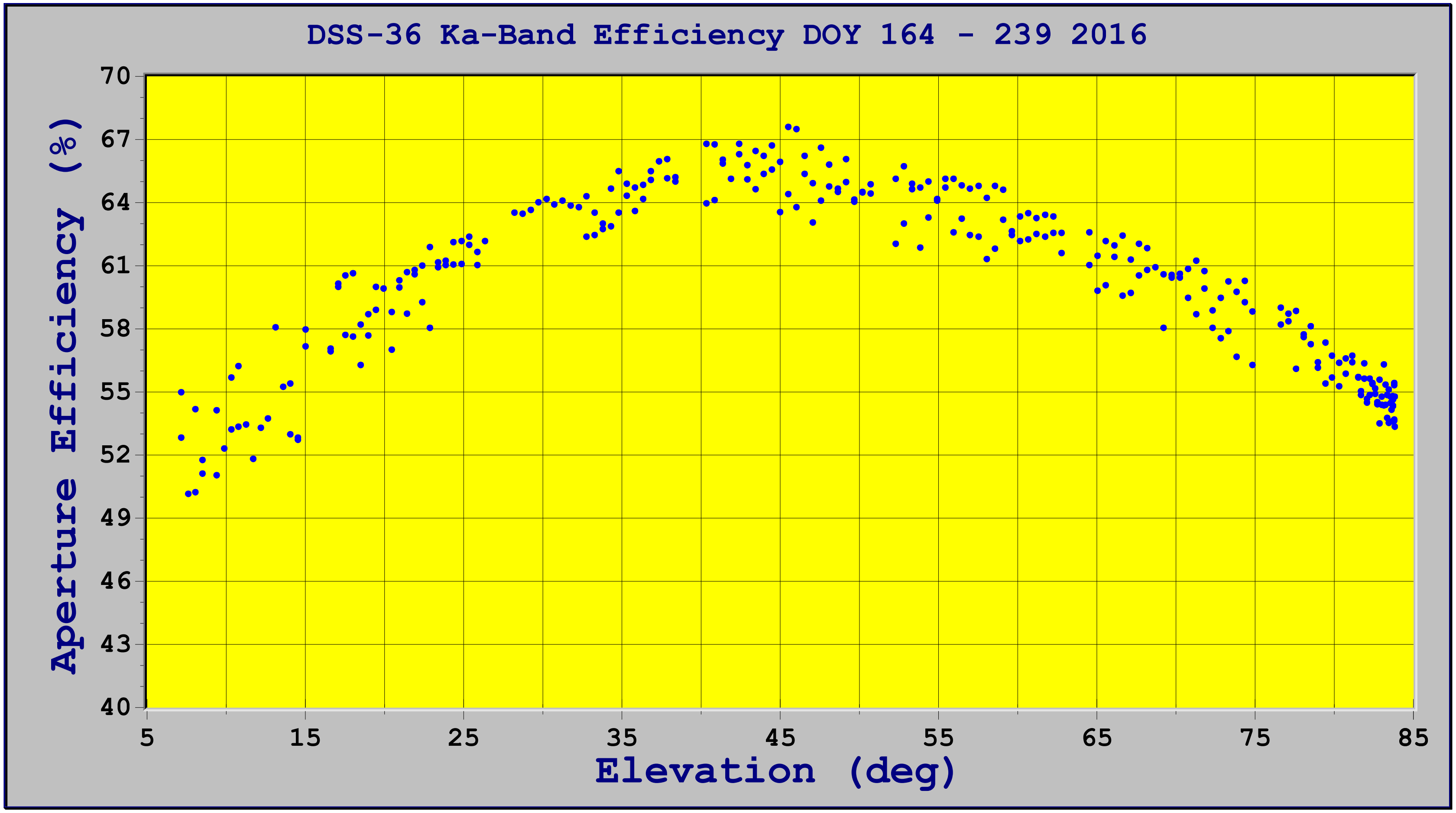
DSS-36 Zenith Noise Temperature

FREQUENCY	CONFIGURATION	POLARIZATION	LINEARITY (%)	T-AMW, ZENITH, ACME (kelvin)	Req. AMW FRD (kelvin)
32.0 GHz	X/X/Ka	RCP	-0.97	13.5	<=18.7
32.0 GHz	X/X/Ka	LCP	-0.07	12.5	<=18.7
8.450 GHz	X/X/Ka	RCP	-0.63	12.73	<=18.5
8.450 GHz	X/X/Ka	LCP	-0.12	14.062	<=18.5
2.295 GHz	S –low noise	RCP	0.43	20.74	<=24.4
2.295 GHz	S/X - Diplexer	RCP	0.43	36.3	<=40.0

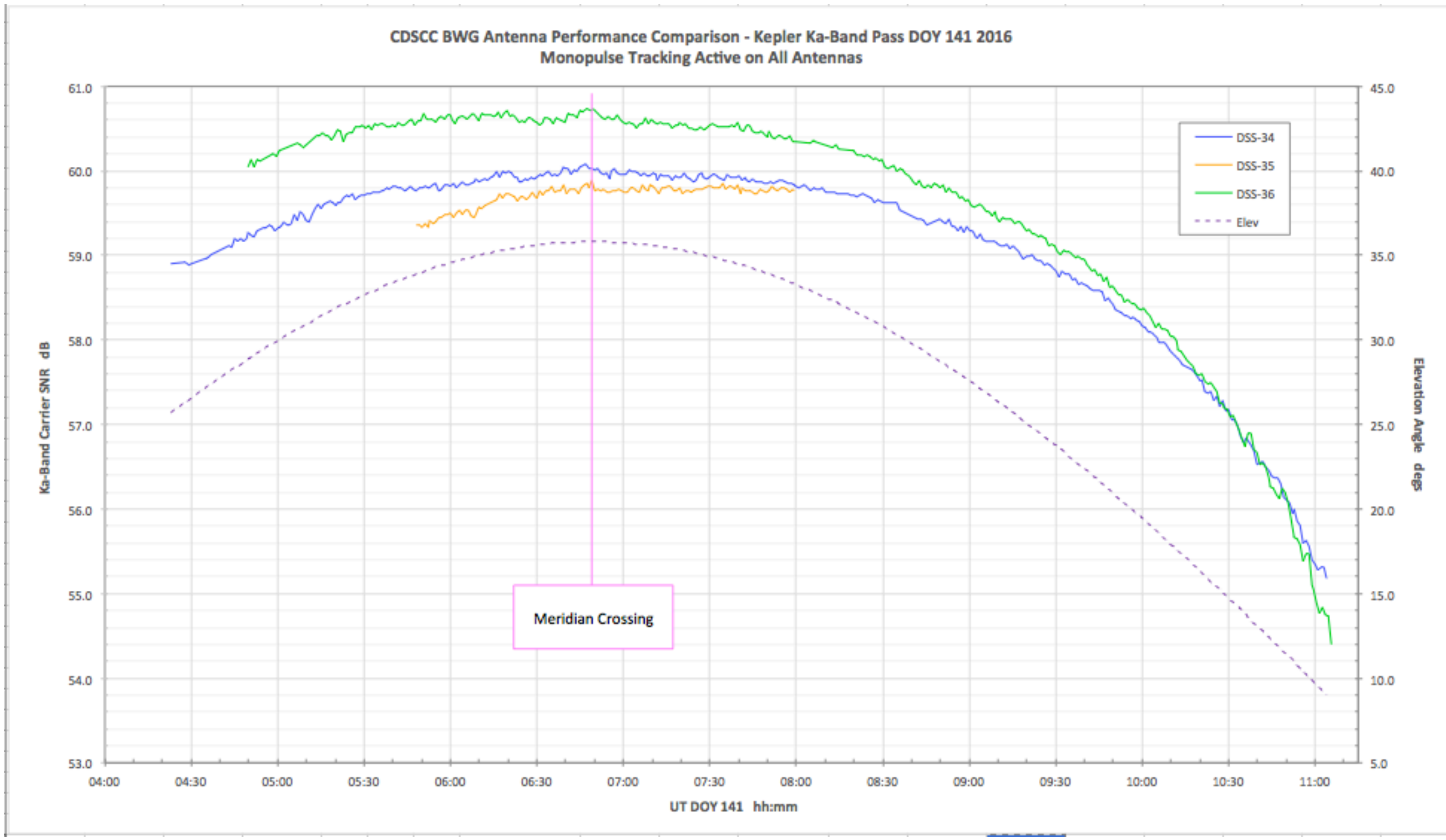
DSS-36 Efficiency and G/T peak performances in Vacuum

Entery	Frequency (Ghz)	RMS F1 (mm)	Efficiency (%)	Tamw (k)	G/T, F3 (dB-k)
Photogrammetry	32.00	0.266	62.03	13.5	67.76
Current Holography	32.00	0.192	66.00	13.5	68.02
Current Holography	8.420	0.192	75.72	12.73	57.27
Current Holography	2.295	0.192	68.9	36.3	41.04

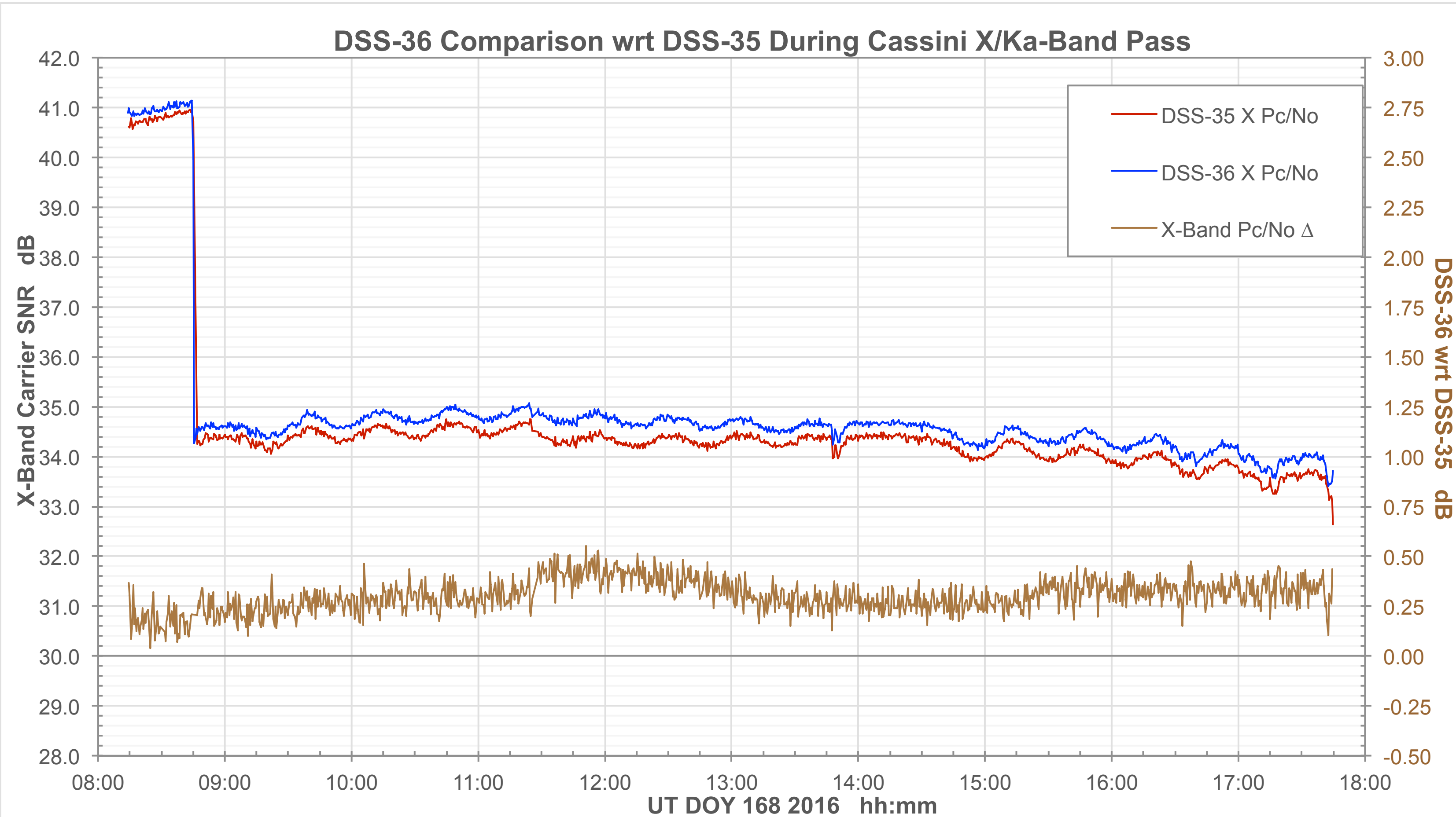
DSS-36 Efficiency at Ka-Band
Exhibiting peak Aperture efficiency of 66% at the rigging angle of 45.5-deg
Elevation Gain Roll-Off at the low / high elevations is 0.87-dB



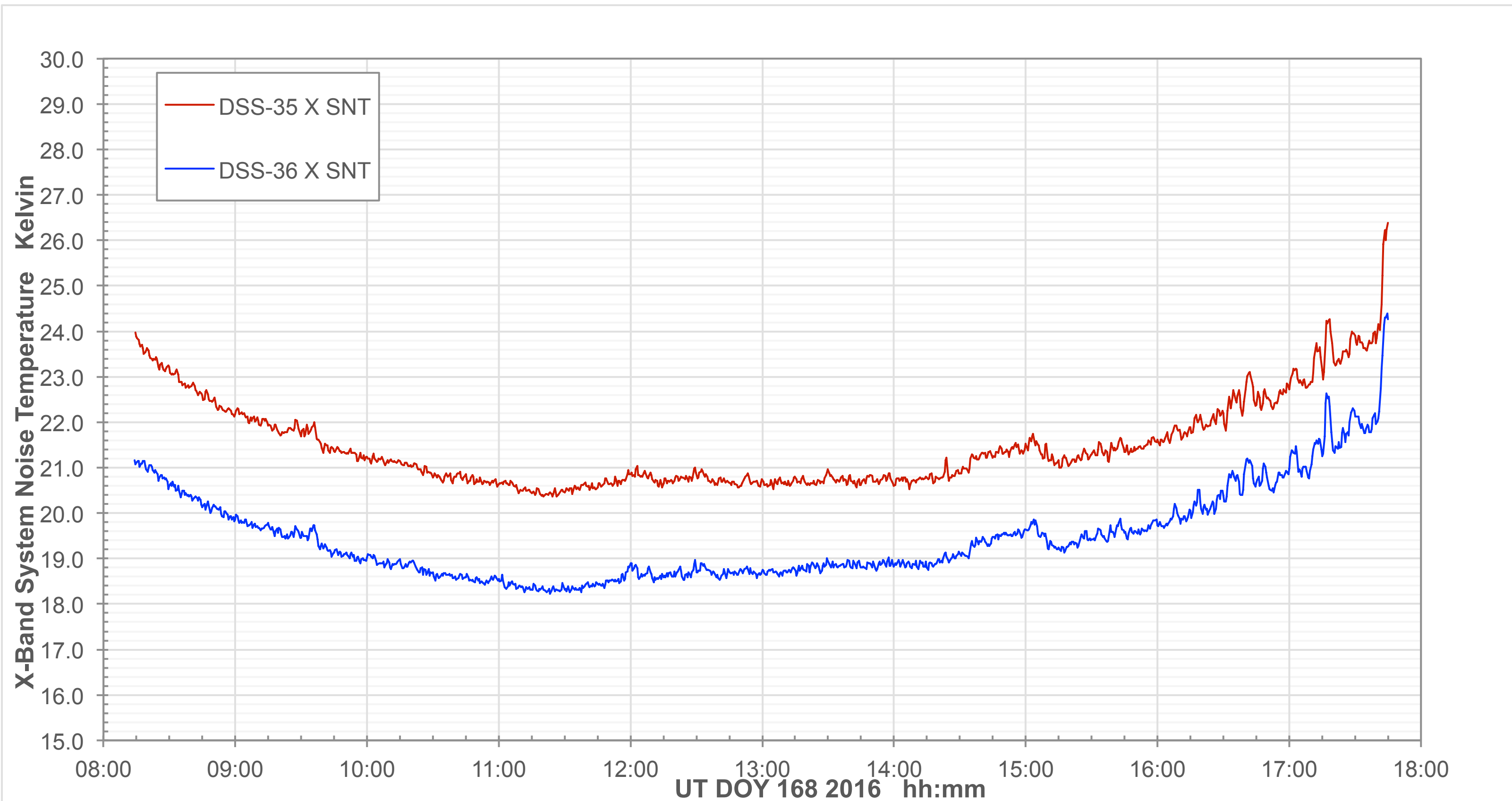
Ka-Band (KPLR) Shadow track DSS-36 vs -35 and -34 with +0.7-dB Pc/No Advantage for DSS-36



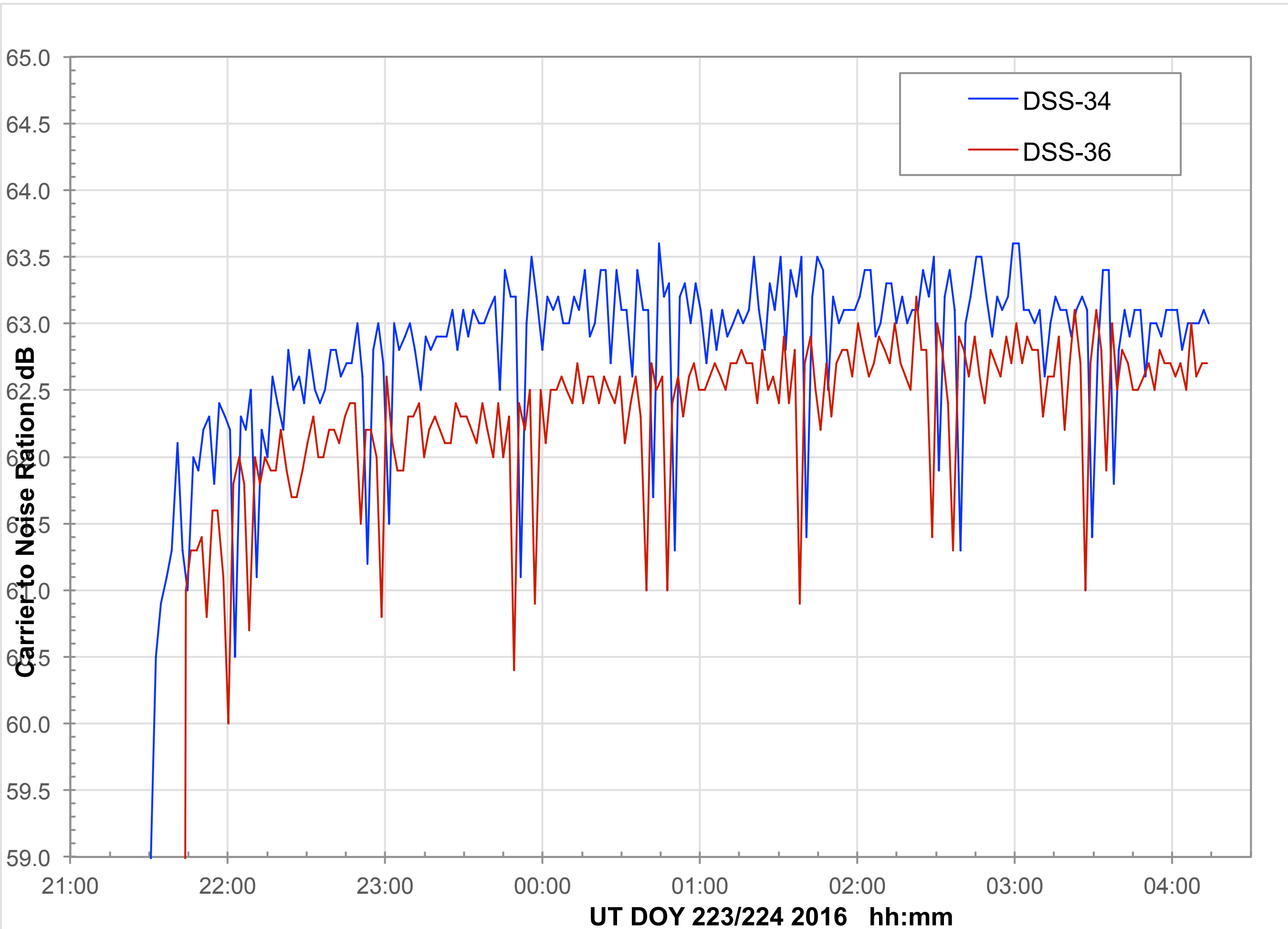
X-Band CAS Shadow track DSS-36 vs -35 with +0.25-dB Pc/No Advantage for DSS-36



DSS-36 Shadow tracks at X-Band against DSS-35 Measuring approx. 2-kelvin lower SNT (agreeing with predictions)



DSS-34 / DSS-36 S-Band SOHO Shadow Pass DOY 233 2016



Tamw DSS-34 =34.46-k

DSS-34 G/T = 41.5-dB-k

Tamw DSS-36 =36.3-k

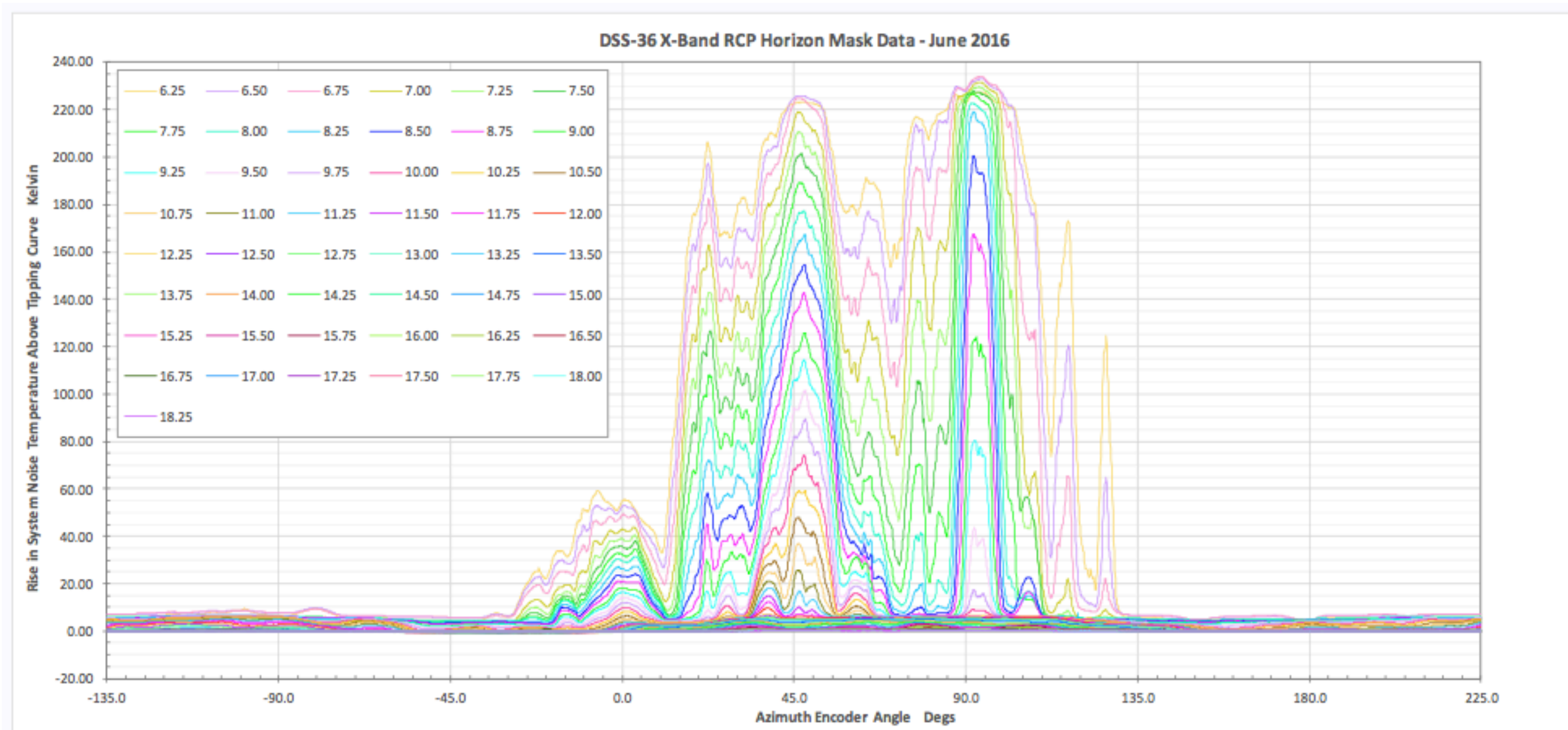
DSS-36 G/T = 41.04-dB-k

Delta G/T = -0.5-dB for DSS-36

Transmit & Receive Horizon Masks
Mask Determination - 1

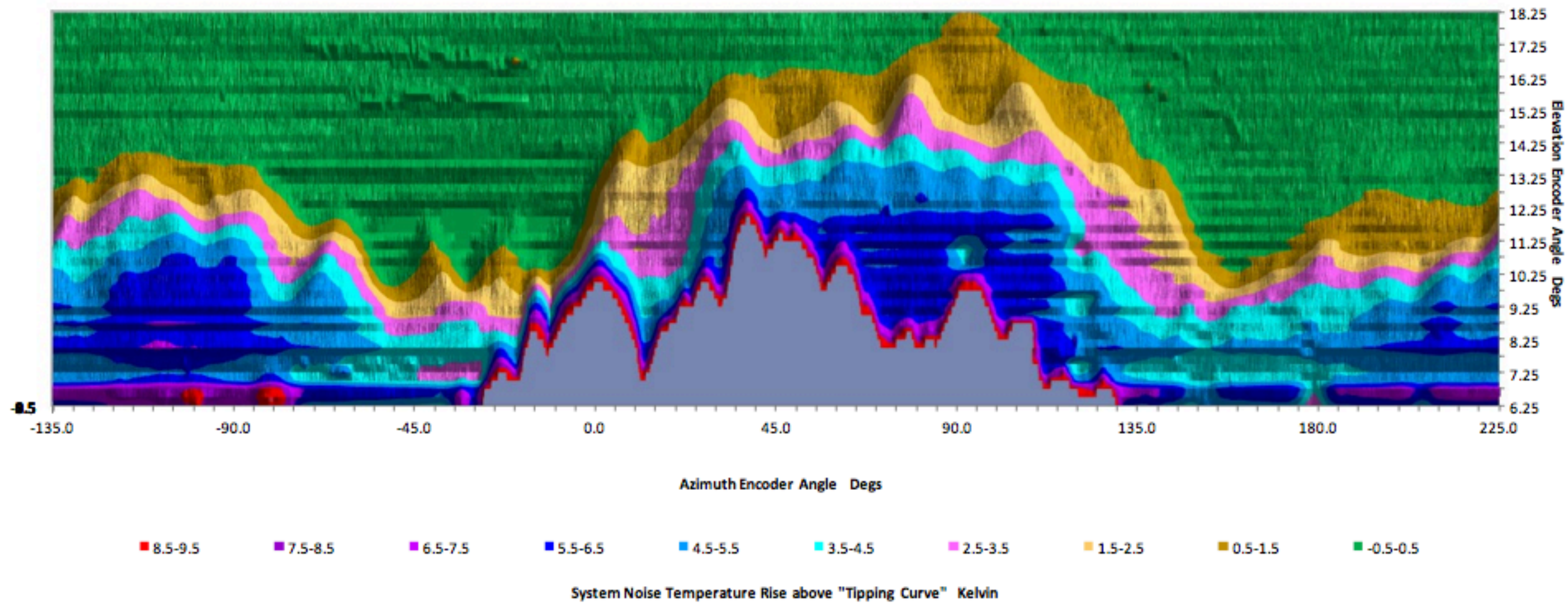
1. The transmit mask is defined as a 2.5 Kelvin increase in SNT above a "conventional" tipping curve – (Tamw + Tsky + cosmic microwave background). ITU regulations stipulate a minimum of 10.5 degrees elevation for a 20kW transmitter.

2. The receive mask is defined as a 50 Kelvin increase in SNT above the same "conventional" tipping curve - ~ 4db loss in link margin.



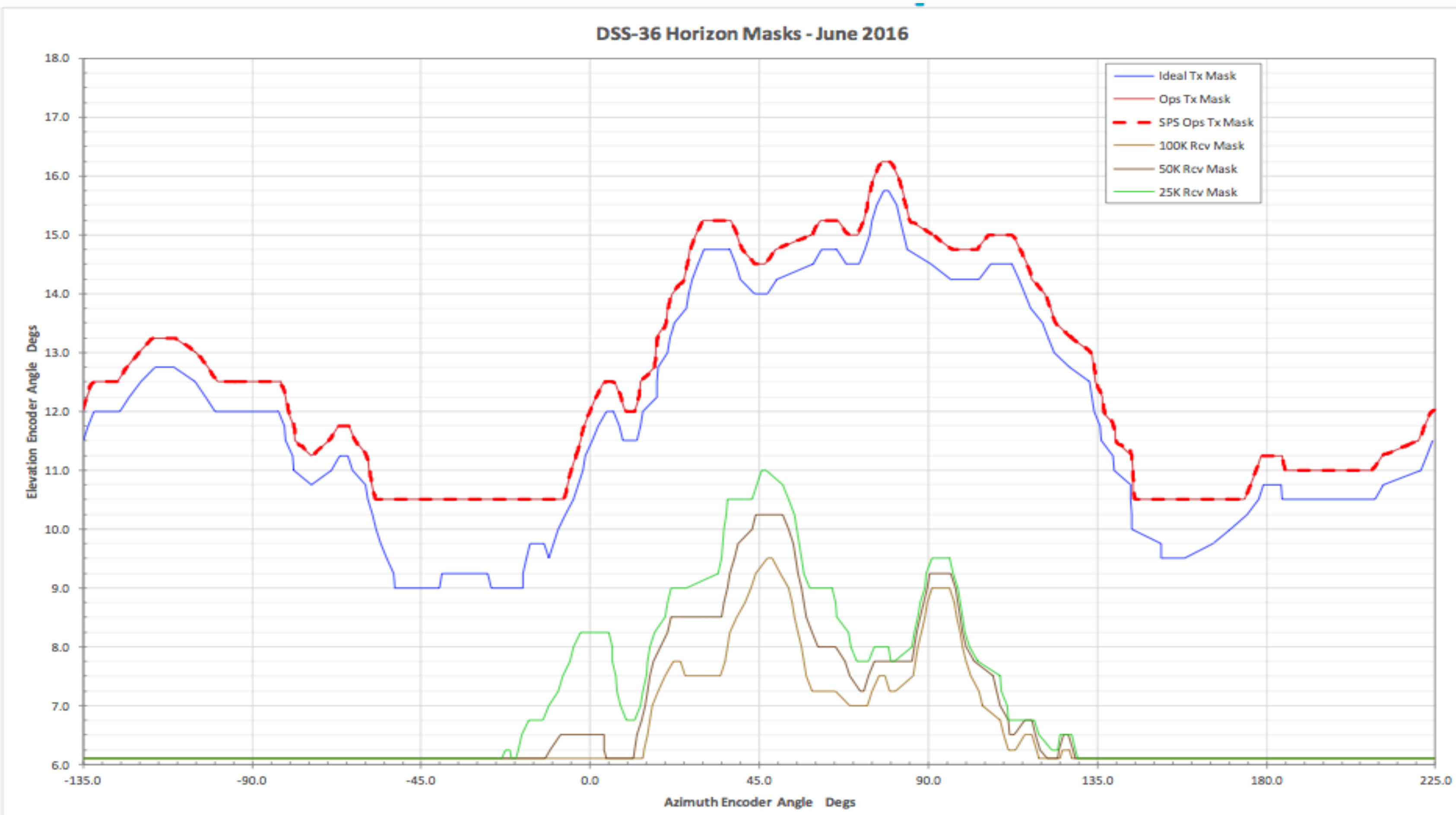
Transmit & Receive Horizon Masks
Mask Determination - 2

DSS-36 X-Band RCP System Noise Temperature Rise Above the “Tipping Curve”
June 2016



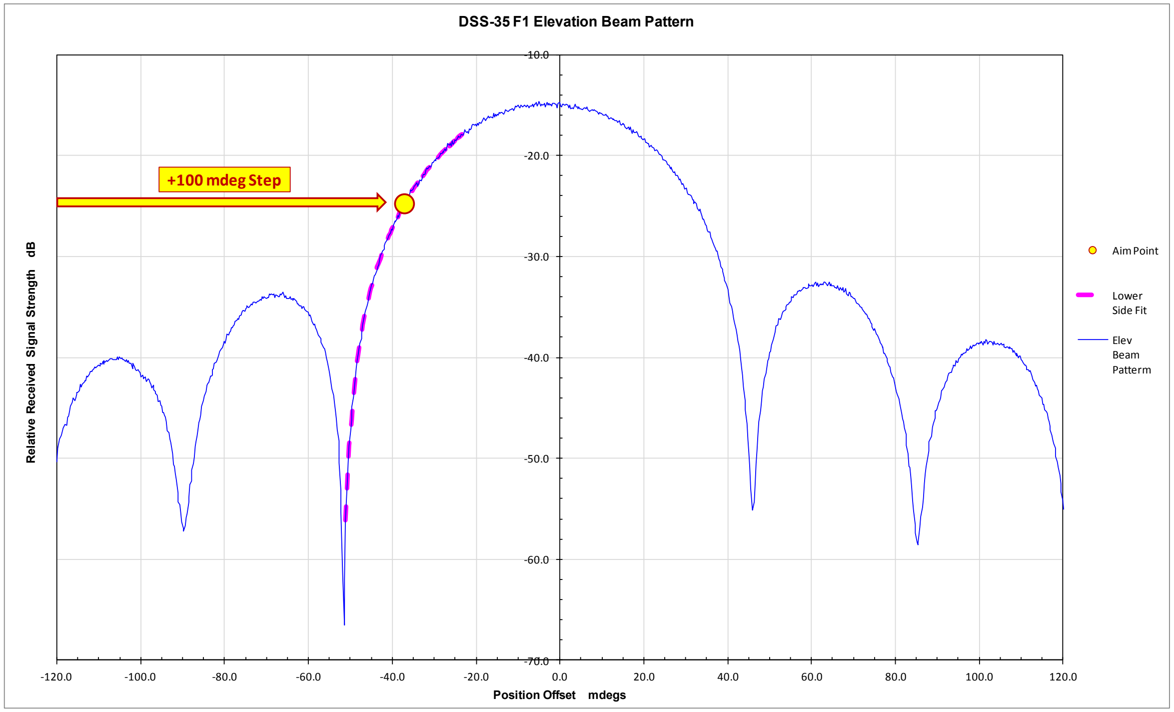
Transmit / Receive Horizon Masks

ATMC Implementation



Principle of RF Beam Measurement

By calibrating the antenna RF beam pattern, the pattern can then be used to determine position change based on measured power. During these tests an "aim" point approximately 10dB down from the boresight position and on the incoming side from the step starting position was chosen to characterize the response. This resulted in about +/-15 mdegs of working range and the best signal strength sensitivity to position change.

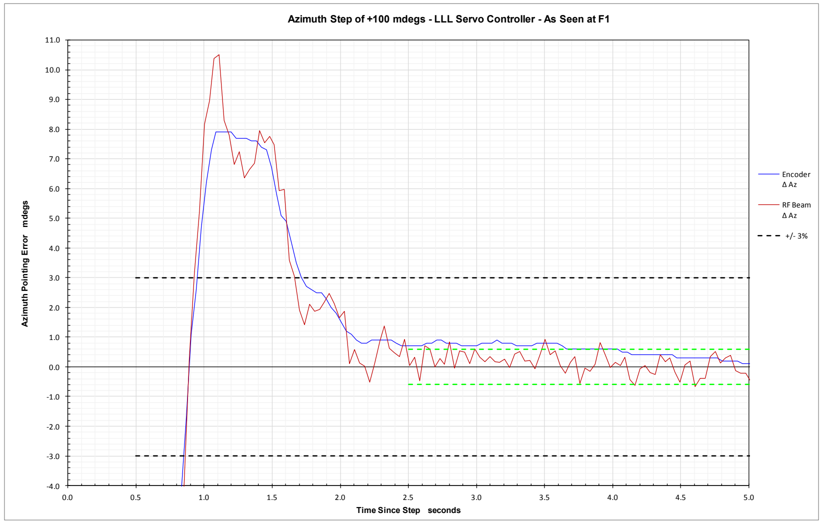


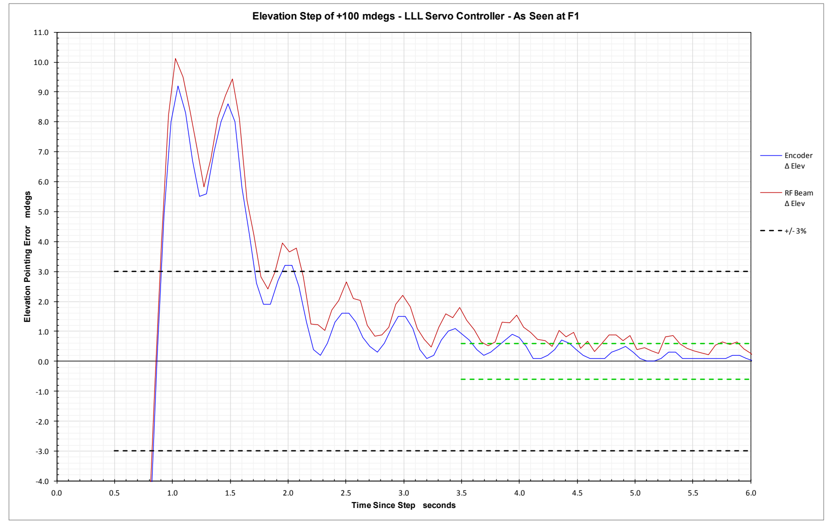
DSS-35 Step Response Test Results Summary

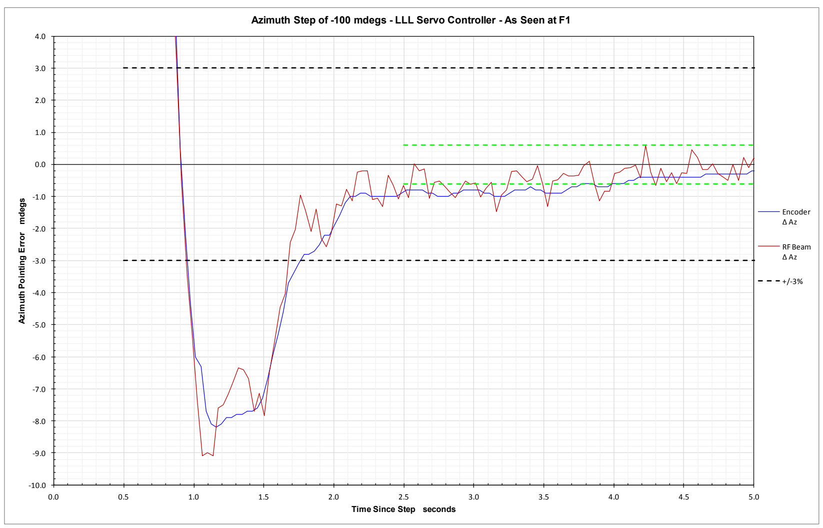
DSS-35 Servo and RF Beam Step Response Tests 18th March 2014	Servo Controller Type											
	LLL						LQG					
	Encoder Response			RF Beam Response			Encoder Response			RF Beam Response		
	Over-shoot (mdegs)	Within +/- 3% of Step Size (Seconds)	Within +/- 0.6 mdegs of Final Position (Seconds)	Over-shoot (mdegs)	Within +/- 3% of Step Size (Seconds)	Within +/- 0.6 mdegs of Final Position (Seconds)	Over-shoot (mdegs)	Within +/- 3% of Step Size (Seconds)	Within +/- 0.6 mdegs of Final Position (Seconds)	Over-shoot (mdegs)	Within +/- 3% of Step Size (Seconds)	Within +/- 0.6 mdegs of Final Position (Seconds)
Azimuth Step of +100 mdegs	7.9	1.71	4.04	10.5	1.67	2.98	15.8	4.76	6.66	16.1	4.65	6.55
Azimuth Step of -100 mdegs	-8.2	1.77	3.68	-9.1	1.68	3.98	-15.8	4.74	6.60	-14.8	4.50	5.85
Elevation Step of +100 mdegs	9.2	2.05	4.44	10.1	2.12	5.88	10.2	5.53	5.75	12.5	5.74	14.25
Elevation Step of -100 mdegs	-9.2	2.09	4.48	-9.3	1.72	4.08	-10.2	5.25	7.19	-11.6	5.45	9.98

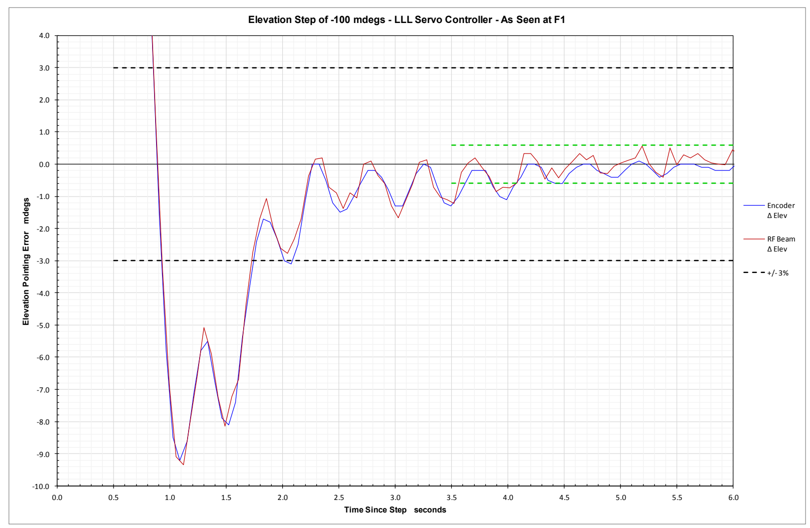
Note: The "Within +/- 0.6 mdegs of Final Position" data reported here is included because this is the pointing tolerance if the step had been 20 millidegrees (+/- 3% of 20 millidegrees).

DSS-35 LLL Step Response Plots

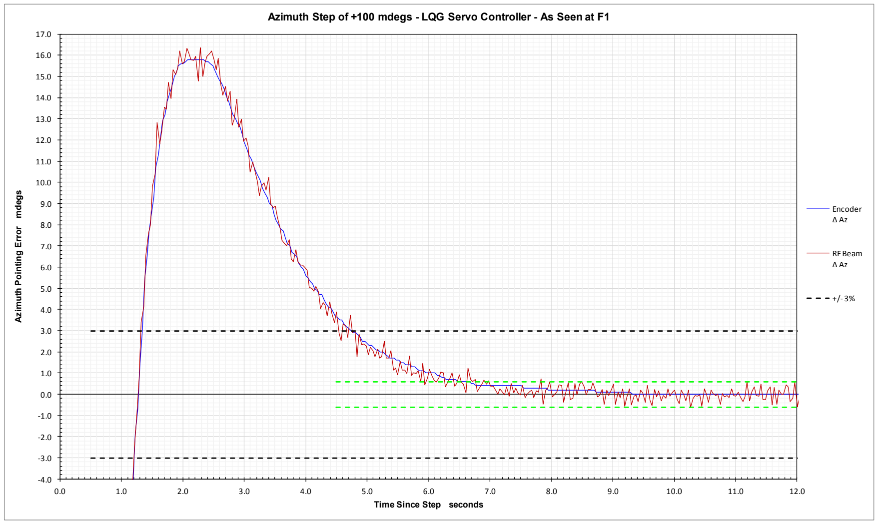


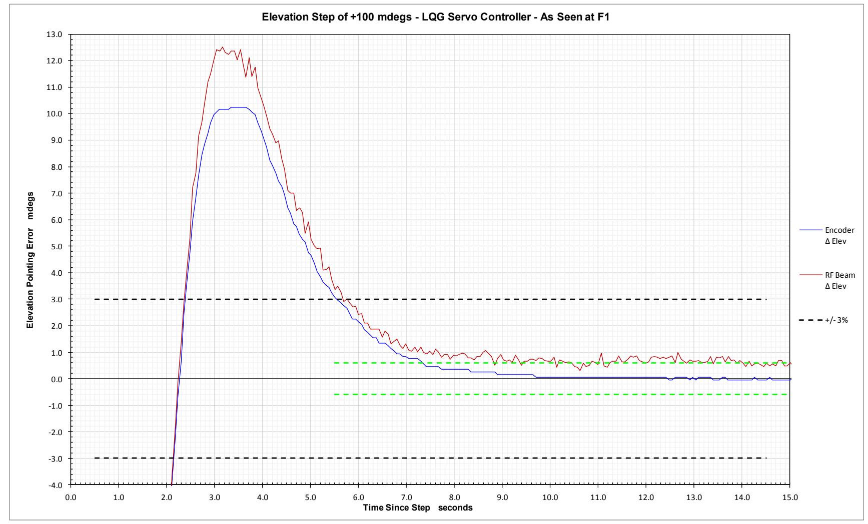


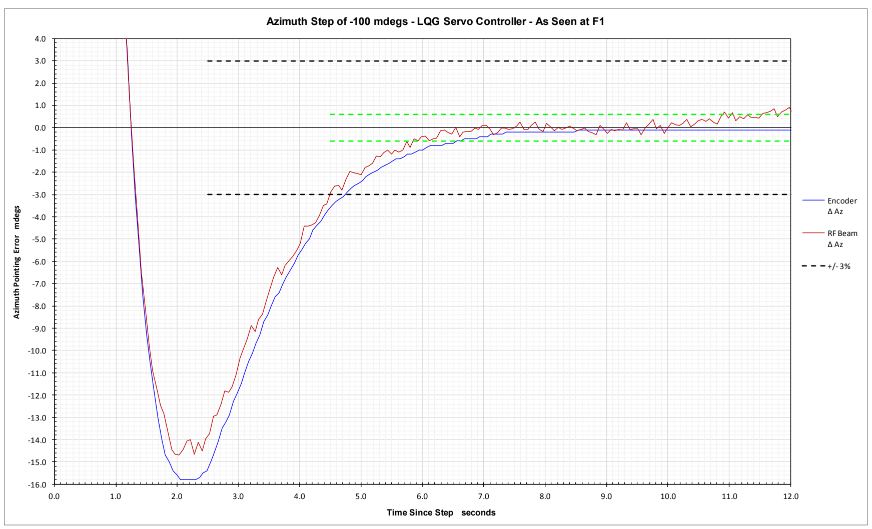


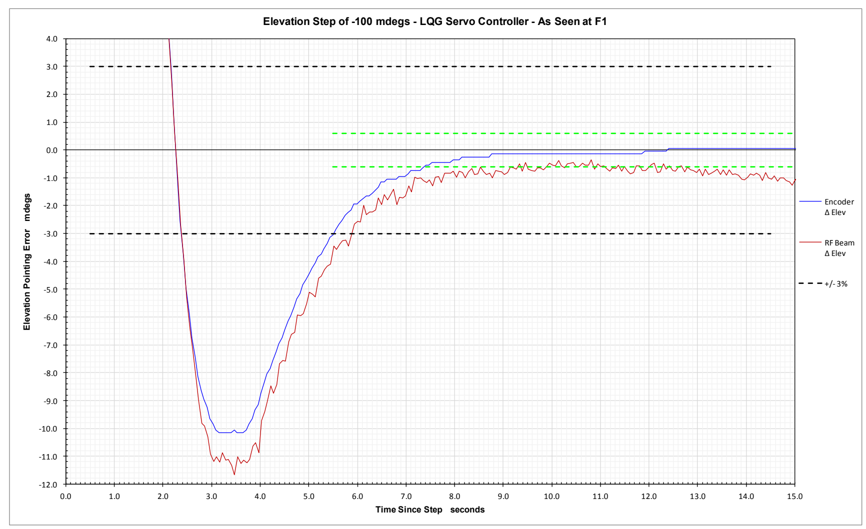


DSS-35 LQG Step Response Plots





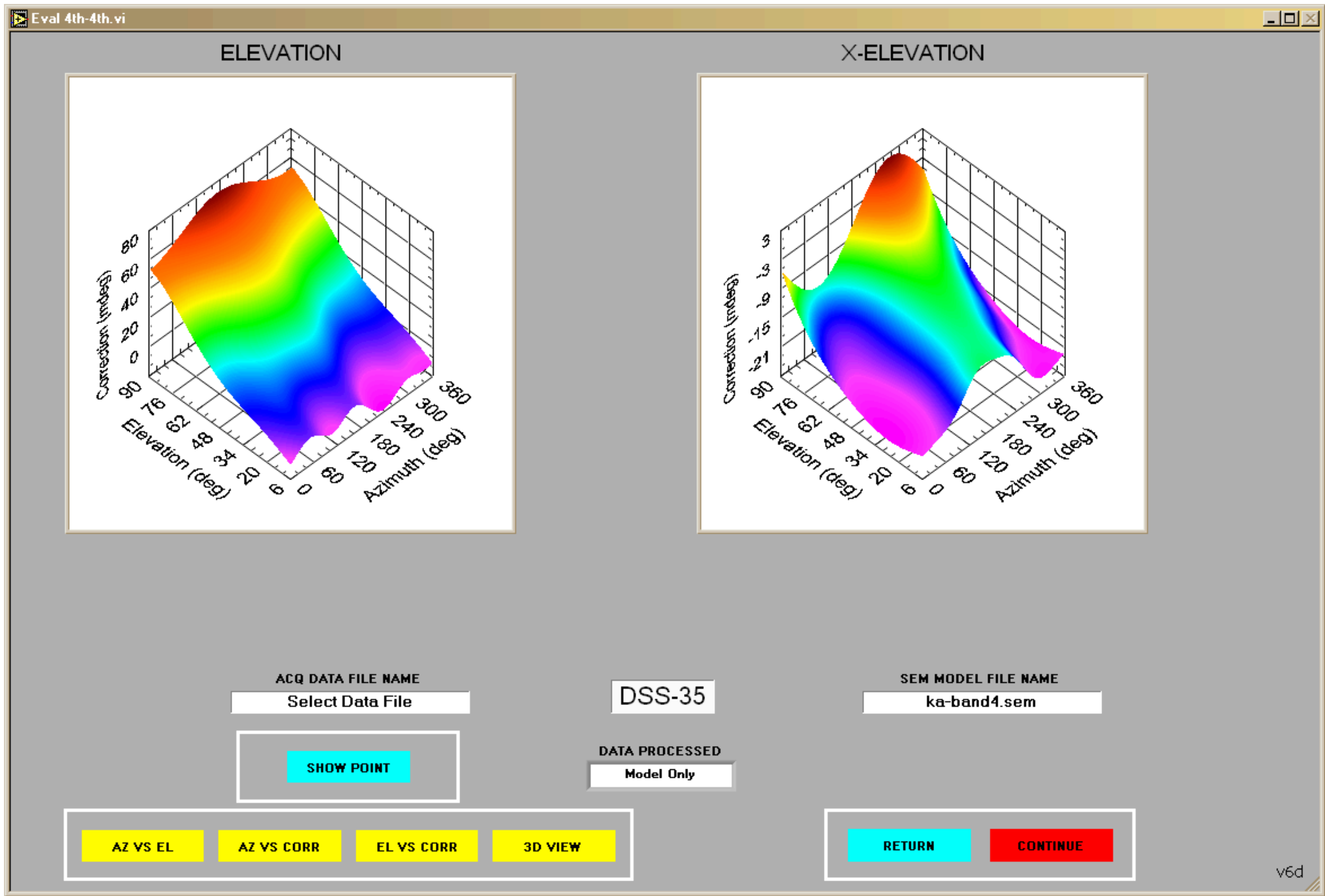




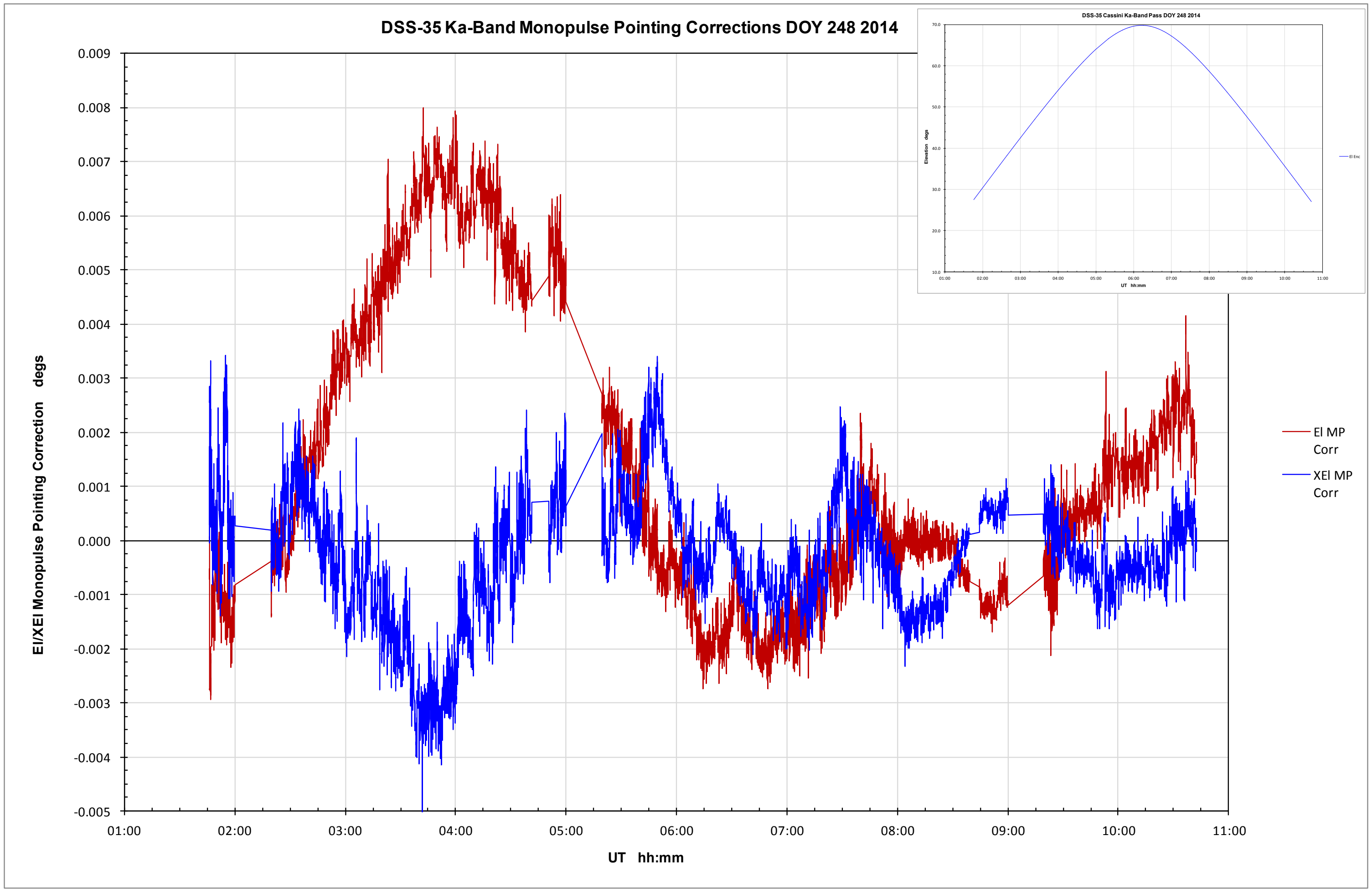
DSS-35 Servo Step Response Tests

As part of the DSS-35 antenna positioning system performance evaluation, servo system step response tests were conducted using both of the available positioning controller types (LLL and LQG). The evaluation was conducted by looking at both the positioning loop (angle encoder) response and the RF beam response as derived from "side-of-main-beam" tracking of a strong geosynchronous spacecraft beacon signal. The later technique used an adaptation of the DSN holography equipment set to gather the response data and required considerable post-data processing to derive the results.

Pointing Models
A single 4th Order Pointing Model servicing All Frequencies and Polarizations at X / Ka-Bands, with Performance better than 4.0 / 8.0-mdeg MRE respectively for the X/ Ka-Bands



Pointing Models (Con't)
Performance on DOY 248, 2014 during a CAS pass
MRE = 2.51-mdeg



Pointing Models Operational Performances at Ka-Band in 2014:

CAS DOY 248:	2.51-mdeg MRE
KEPL DOY 233 :	3.4-mdeg MRE
CAS shadow tracks on DOY 137 and 159:	3.5-mdeg MRE