





NRF National Research Foundation | SARAO South African Radio Astronomy Observatory

CONVERSION OF A DISUSED EARTH SATELLITE STATION FOR RADIO ASTRONOMY : STRUCTURE AND CONTROL SYSTEM

AFRICAN VLBI NETWORK

PRESENTER: Japie Ludick

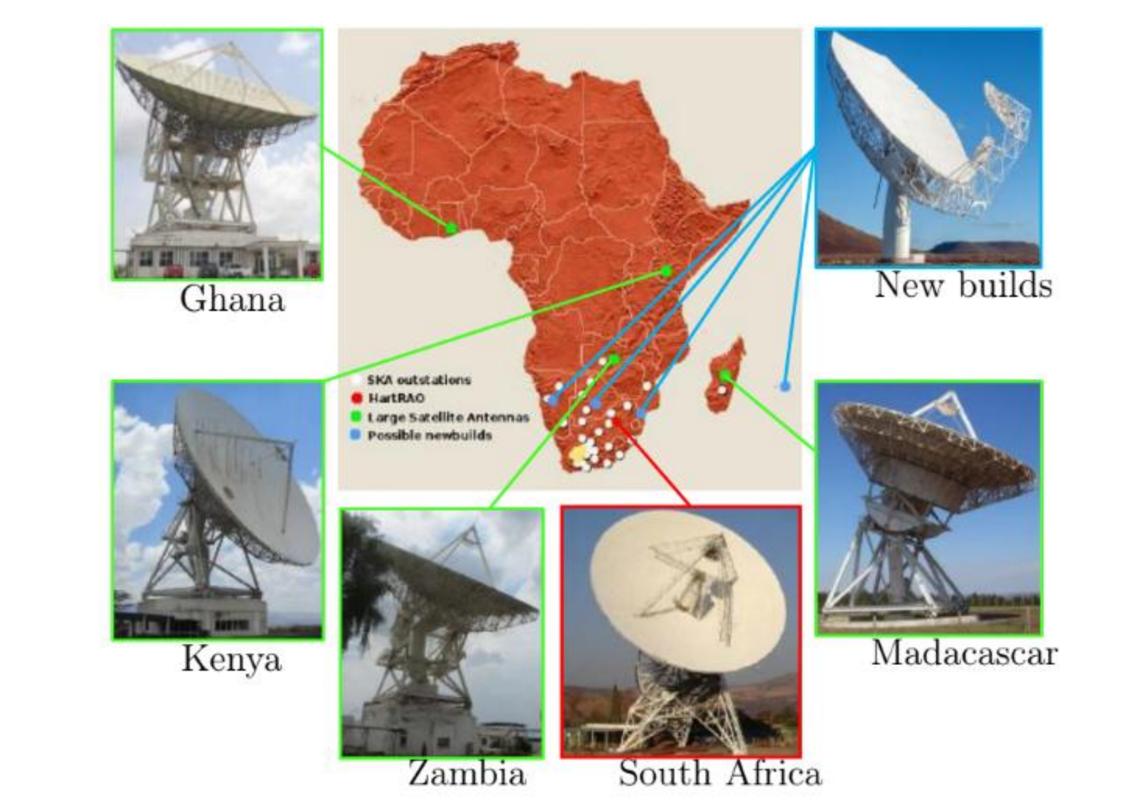
Contents

- Background
- Conversion Process
- Major Modifications
- Performance predictions
- Issues / Current Developments

Background

African VLBI Project

- African VLBI Network (AVN)
- Conversion / New build
- Readiness for SKA



Background

Ghana Conversion

- Kuntunse Antenna (25 km N of Accra, Ghana)
- Built in 1979 – TIW Systems /Spar (Canada) - GDSatcom
- One of 9 similar antennas around the world (INTELSAT)
- Out of service since 2007 (Vodafone)

Background

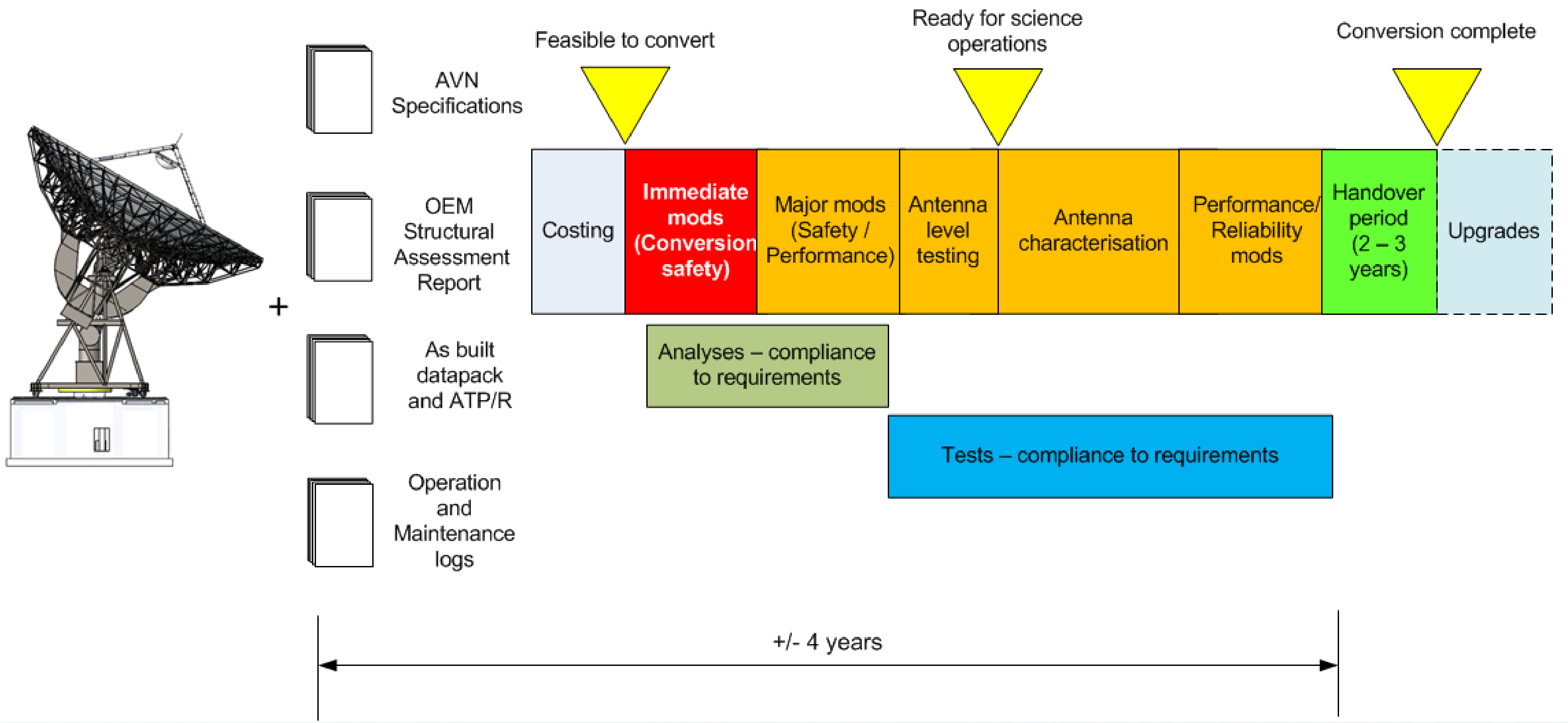
- Crane collapsed during BUS lift (19 Mar 1980)

Background

Main Characteristics of Antenna Structure

- 220 Ton wheel and track, Beam Wave Guide
- 32m Diameter (F/D = 0.32)
- Elevation operational range 5 to 85 deg
- Azimuth (-8 to 327 deg wrt N)
- Dual drive on sector gear (elevation)
    - Elevation slew rate (0.27 deg/s @ motor rated speed)
- Dual drive on wheel/track (azimuth)
    - Azimuth slew rate (0.29 deg/s @ motor rated speed)
- Max operational wind speed (80mph – de-rated to 30mph for commissioning)
- Survival at stow (120 mph)

Conversion process (ideal)



Antenna Specifications

Conversion from Telecoms to Radio Astronomy Role

Feature	Original Specification / Role	Deterioration	AVN Specification at 18 GHz	Modification(s)
Main reflector surface accuracy @ 60°	0.12 mm RMS	Damage/repairs/ removals	1.3mm RMS (η= 0.4)	Holography measurements + adjustments if required
Elevation slew rate	0.27°/s	N/A	0.27°/s	Servo motors (0.38°/s max)
Azimuth slew rate	0.29°/s	N/A	0.29°/s	Servo motors (0.41°/s max)
Lifetime	30 years	38 years (last 10 years not operational)	15 years since conversion	• Corrosion treatment • Repainting of entire structure • Pintle bearing pad upgrade/replacement • Updated maintenance schedule/training/reporting

Antenna Specifications

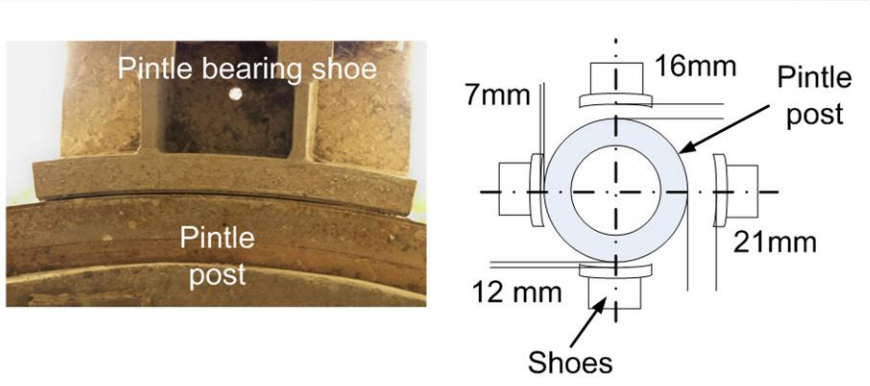
Continued

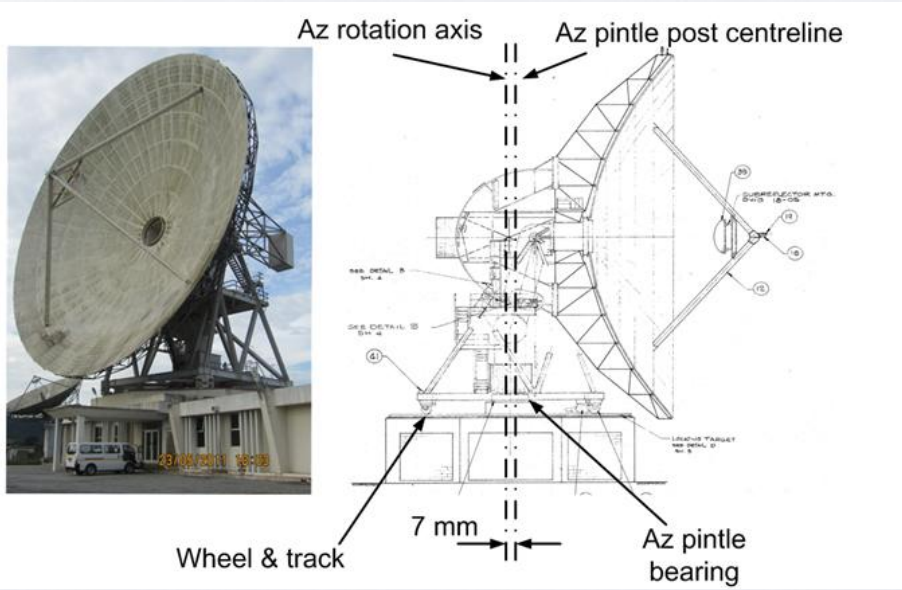
	Original Specification / Role	Deterioration	AVN Specification at 18 GHz	Modification(s)
Azimuth concentricity	N/A	Pintle bearing pads worn out	< 4.3mm	- Lifting and re-centring of antenna structure - Concentricity monitoring - Full 360° azimuth pintle bearing
Duty cycle	Geostationary telecoms	Virtually stationary	Radio-astronomy – 500, 000 cycles (VLBI + Single dish HartRAO)	- Quad leg / subreflector support replacement - Azimuth pintle bearings – intermediate - Azimuth pintle bearings permanent
Azimuth Range	+/-170° from due South	Maintenance	-8° CCW / 327° CW from North	+/- 305° from North
Pointing accuracy	0.0025°	Track level?	0.0018°	Antenna Steering Control System (including track level compensation)
Tracking accuracy	0.0025°	Track level?	0.0048° RMS (Initial)	Antenna Steering Control System (including track level compensation)

Major Modifications

Antenna Centring

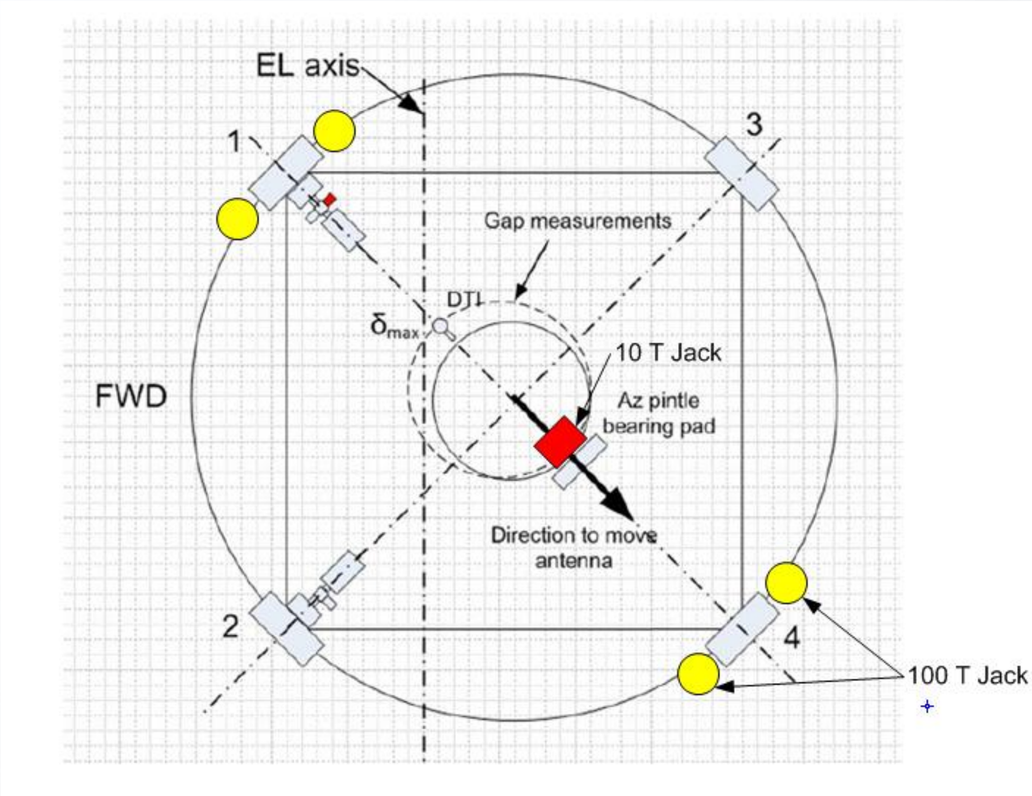
Unconventional pintle bearing – 4 pintle “shoes”





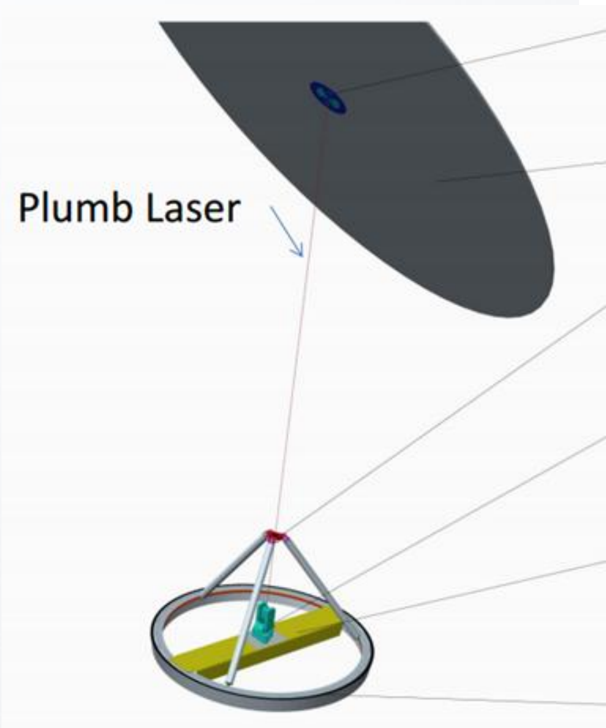
Major Modifications

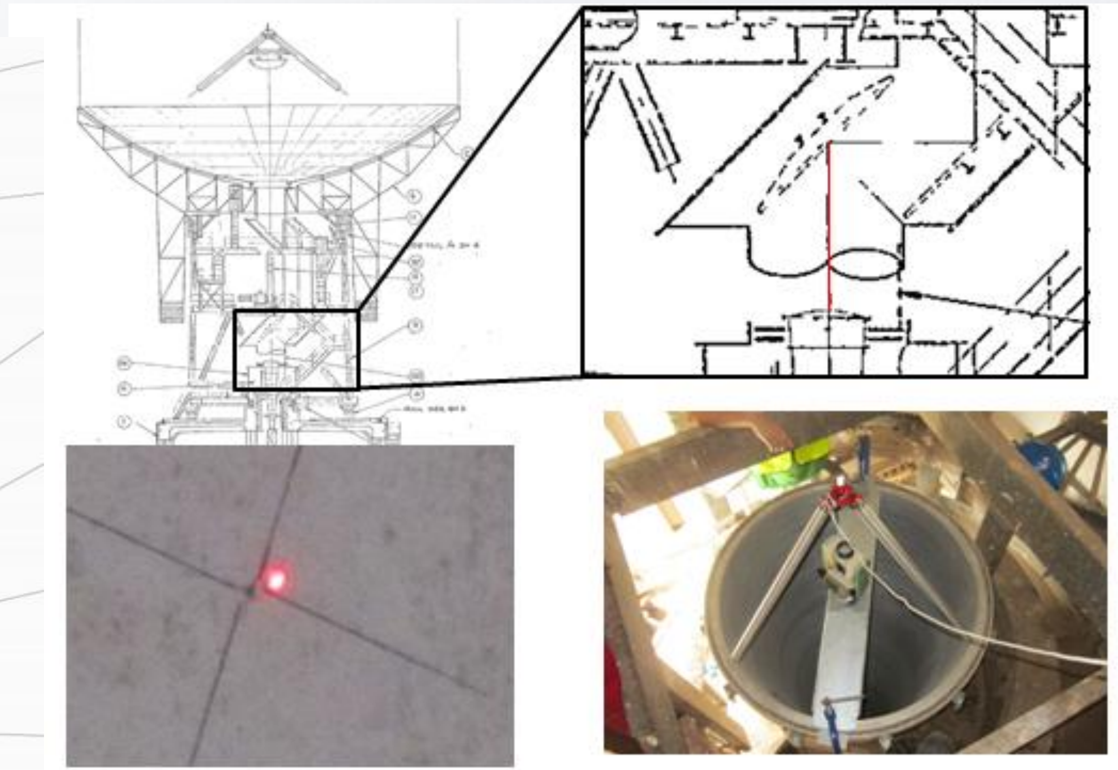
Antenna Centring



Major Modifications

Antenna Centring





Major Modifications

Shock absorber / structure replacement

Major Modifications

Corrosion treatment and re-painting

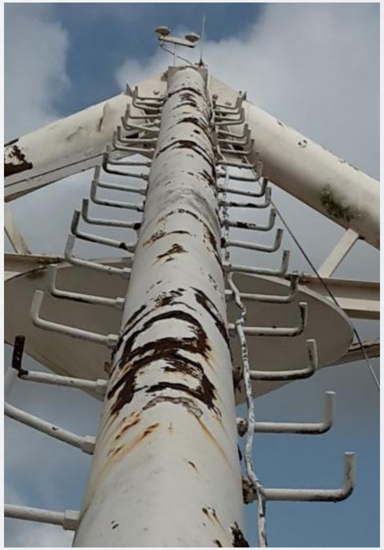
- Stripped down to bare metal at corroded areas
- Pre-primed (Al filled epoxy Interseal 670 HS) – bare metal areas
- Primed (Al filled epoxy paint – Interseal 670 HS) – everywhere
- Intermediate coat (Epoxy – Interseal 670 unfilled) – everywhere
- Top coat (Polyurethane Interthane 990)- Everywhere except
  - Quad leg internal diameter
  - Beam wave guide internal diameter
- +/- 2400 Liters of paint (4 months – crew of 10 people)

Major Modifications

Corrosion treatment and re-painting

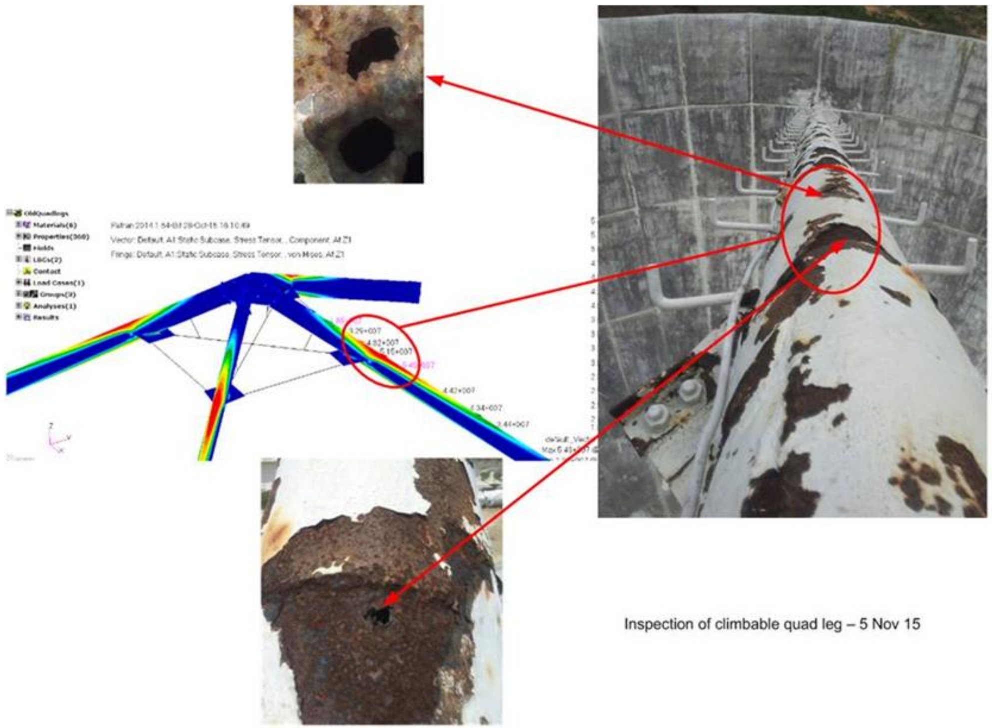
Major Modifications

Quad leg structure / subreflector support frame

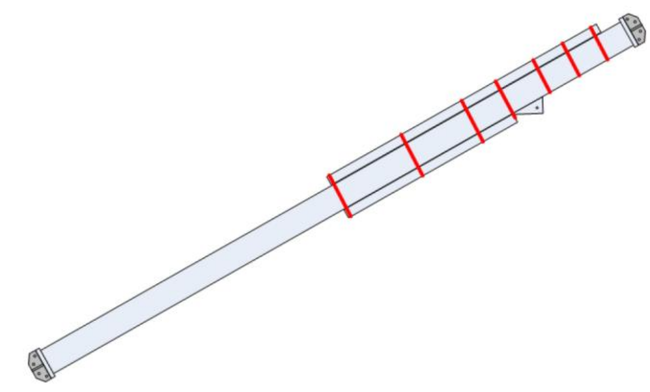


Major Modifications

Quad leg structure / subreflector support frame



Inspection of climbable quad leg – 5 Nov 15



Major Modifications

Quad leg structure / subreflector support frame

- Re-manufacture in Ghana using GAEC workshop and staff
- Re-engineered to suit manufacturing facilities and bending stiffness (circular vs. elliptical)
- Impose limitation of 70 deg elevation movement due to safety concern during development
- Circular sections (qty = 32) rolled from flat plate sourced in Ghana
- 2 people produced entire structure over 4 month period
- Major QA/QC effort

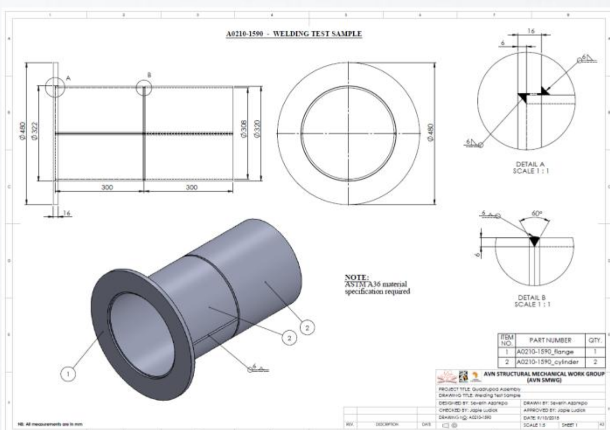
Major Modifications

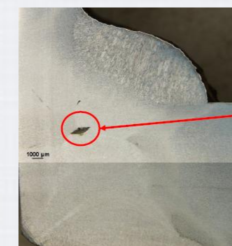
Quad leg structure / subreflector support frame - QA

- Quality Assurance / Quality Control
  - Material Certification (South Africa)
  - On site - weld process recording
  - Weld qualification samples
  - Weld quality NDT - 3 weld configurations(South Africa)
  - Welder certification to AWS D1.1
  - 100% dye penetrant / 100% X-ray inspection (circular welds)
  - 100% dye penetrant / 10% X-ray inspection (longitudinal welds)
  - 100% dye penetrant (pipe to flange / gussets) – AWS certificated weld visual inspection

Major Modifications

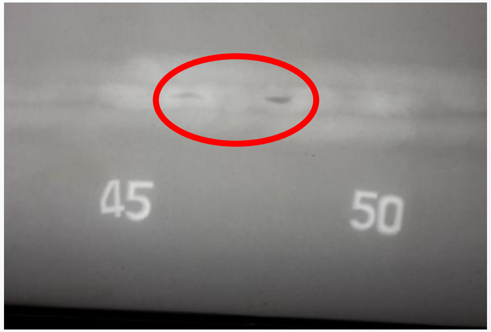
Quad leg structure / subreflector support frame - Training

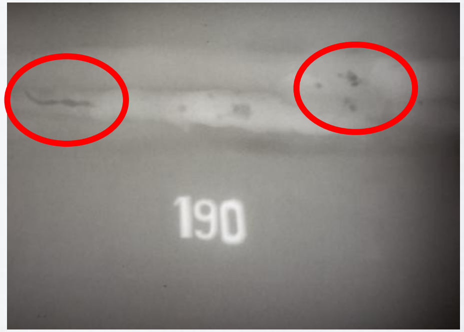


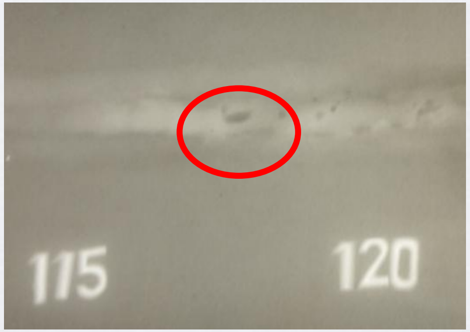


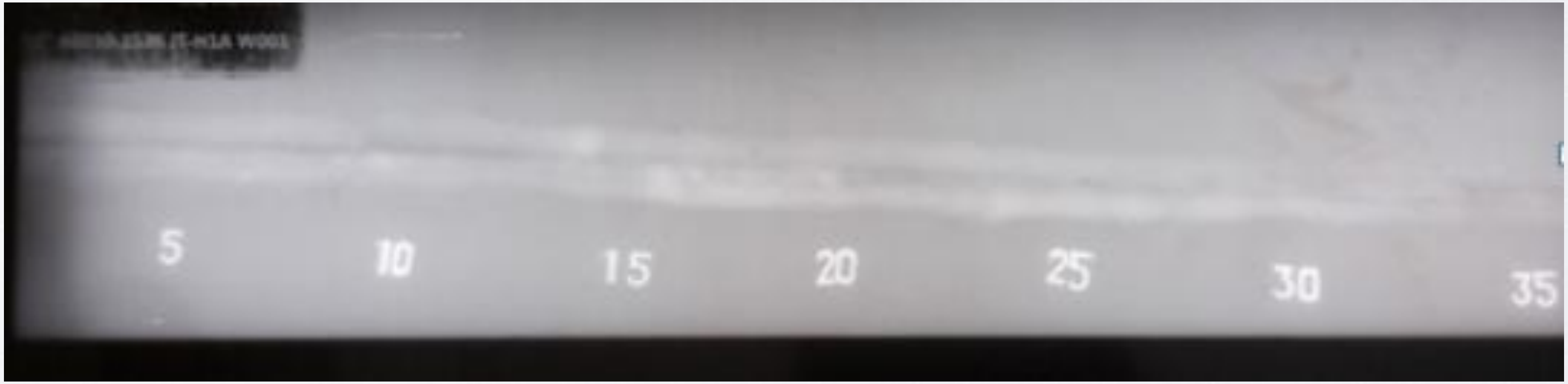
Major Modifications

Quad leg structure / subreflector support frame - Training









Major Modifications

Quad leg structure / subreflector support frame – Training & Certification

WELDER PERFORMANCE QUALIFICATION

Issued by: RBI Tech

P.O. No.:	*Item:*
Ref.:	*Item No.:*

General

Employer	: ***Square Kilometre Array (SKA Africa)***	Welder	: S. Saad
Designation	: Welder	Identity No.	: G1155703
Identification Method	: Passport	Stamp Number	: SS
Date Of Birth	: 29-Nov-79	Certification No.	: 16/01/8730
Place of Birth	: Accra		
Job Knowledge	: Not tested		
Code / Testing Standard	: AWS D1.1 - 2015		

WELDING DETAILS

Welding Process	: SMAW
Process Type	: Manual
WPS Followed	: WPS SKA001/W Rev. 0
Material 1	: ASTM A36
Thickness	: 5.0 mm
Material 2	: ASTM A36
Thickness	: 5.0 mm

VARIABLES	***ACTUAL VALUE***	***QUALIFICATION RANGE***
Backing	: SMAW-None	SMAW-With or without backing only
Material Group-No.	: Group I	Determine a welders ability to produce sound welds
Material Group-No.	: Group I	Determine a welders ability to produce sound welds
Diameter	: None-Plate material	Plate and pipe 600 mm O/D & above
Filler SFA & AWS No.	: SFA A5.1 AWS E7018-1	SFA A5,1 & SFA A5,5
Filler Composition	: C/Mn/Si	C/Mn/Si only
Consumable Insert	: None	With or without inserts
Deposit Thick./Process	: 5.0 mm	3.0 to 10.0 mm CJP & PJP groove welds
Weld Position	: Flat	Flat only CJP & PJP
Weld Progression	: N/A	N/A
Backing Gas	: N/A	N/A
Transfer Mode	: N/A	N/A
Current Type GTAW	: N/A	N/A
Polarity GTAW	: N/A	N/A
Control Method	: N/A	N/A
Joint Tracking	: N/A	N/A
Filler added	: N/A	N/A
Filler Metal Product Form	: N/A	N/A
Remarks	: Visual inspection found to be acceptable & welder qualified with radiography examination	

TEST DETAILS

Bend test: None	***Bend Angle:*** N/A		***Former Size:*** N/A
Type	Result	Type	Results
- -			

RADIOGRAPHY TEST	: Par. 4.9.2.2	REPORT NUMBER:	NDIS RT/SKA/16/008
Result	: Acceptable		
FILLET WELD TEST	: N/A		
Fracture Test (1)	: N/A		
Fracture Test (2)	: N/A		
Defect Length (mm)	: N/A		
Defect %	: N/A		
Macro Test Fusion	: N/A		
Appearance Test Fusion	: N/A		
Appearance Fillet Size	: N/A		
Appearance Fillet Size	: N/A		
Convexity (mm)	: N/A		
Concavity (mm)	: N/A		

CERTIFICATION

WE CERTIFY THAT THE WELDS WERE PREPARED, WELDED AND TESTED SATISFACTORILY IN ACCORDANCE WITH THE REQUIREMENTS OF THE CODE / TESTING STANDARD INDICATED ABOVE, TO THE BEST OF OUR KNOWLEDGE.

MANUFACTURER		**CERTIFIED BY**		
Signature	Date	Signature	2016-03-24 Date	LVUP068

RBI-Tech Job No.: GR/8318 — *Certificate No.: 16/01/8730*

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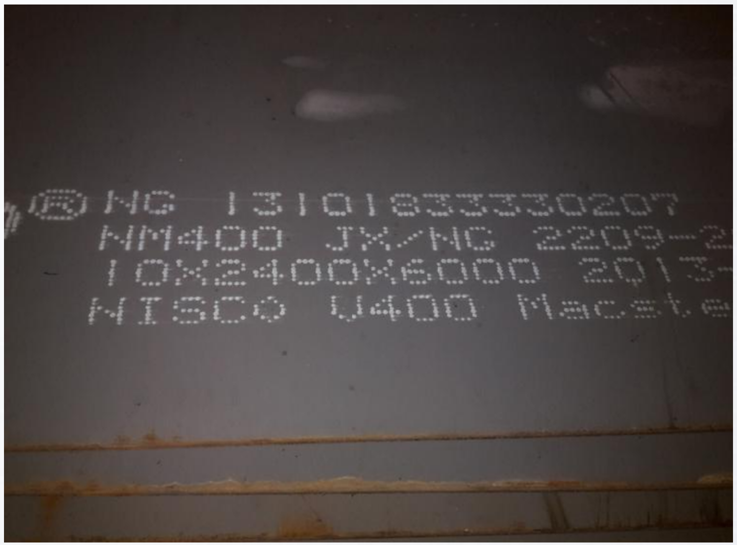
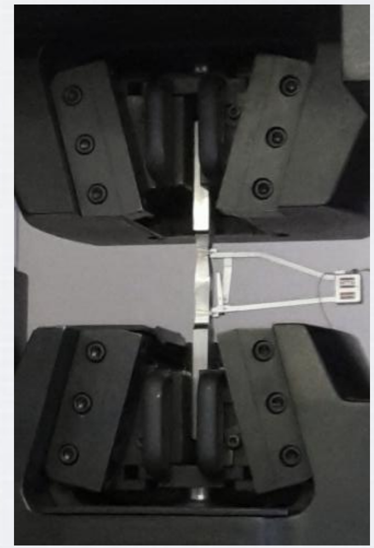
Major Modifications

Quad leg structure / subreflector support frame – Material Certification





TENSILE TEST (acc. to AWS D1.1 4.9.3.4)										
Specimens	Direction	Width	Thickness	Area	Gauge	Yield Load	$R_{T0.2}$ Yield	Max Load	R_m UTS	Elongation
No.	Trans. / Long.	(mm)	(mm)	(mm^2)	(mm)	kN	(MPa)	kN	(MPa)	(%)
Pipe Specimen 1	Transverse to weld	11.96	5.86	70.09	50.00	19.84	283.08	31.60	450.88	26.18
Pipe Specimen 2	Transverse to weld	11.99	5.87	70.38	50.00	21.02	298.68	31.75	451.17	29.34
Acceptance Criteria acc. to AWS D1.1 4.9.3.5: min UTS of base material ASTM A36							250 min		400-500	22 min

Major Modifications

Quad leg structure - manufacturing

Major Modifications

Quad leg structure - manufacturing

Major Modifications

Quad leg structure - manufacturing






Major Modifications

Quad leg structure - manufacturing



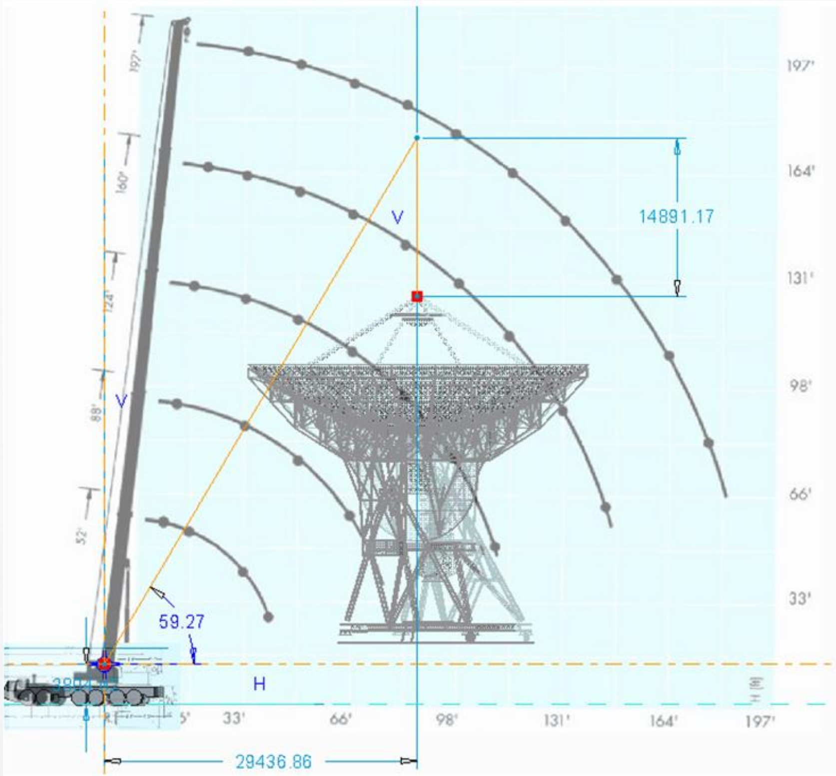


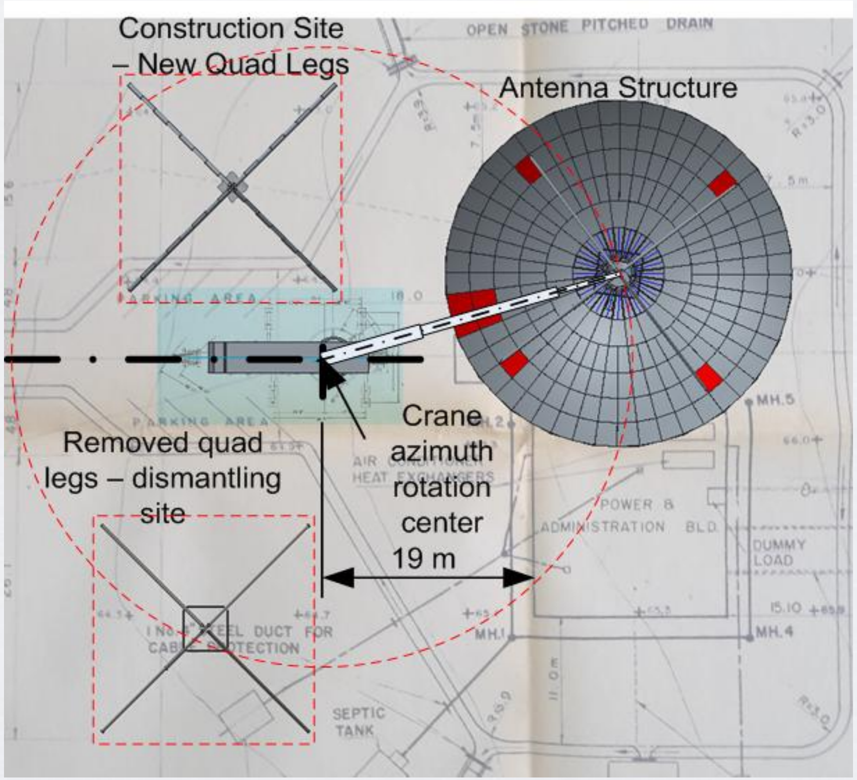

Major Modifications

Quad leg structure - manufacturing

Major Modifications

Quad leg structure - replacement



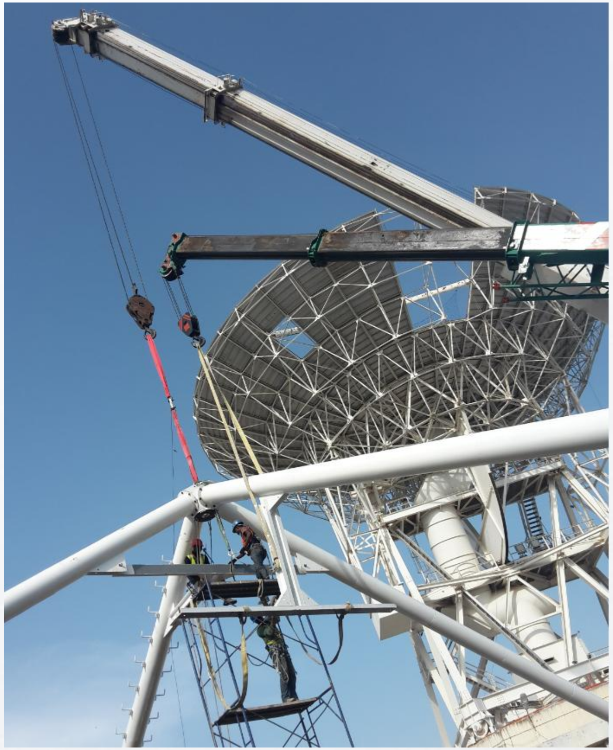


Major Modifications

Quad legs - installation

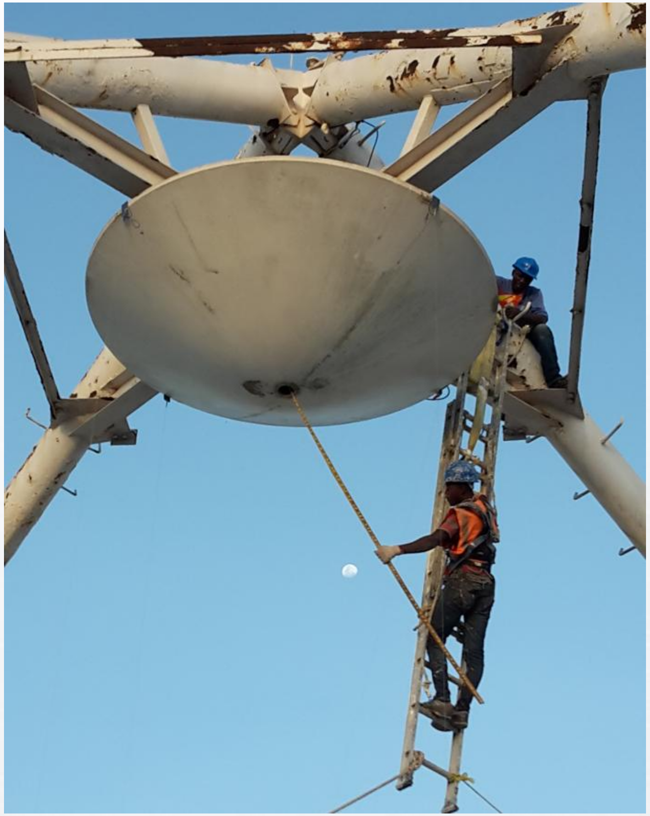
Major Modifications

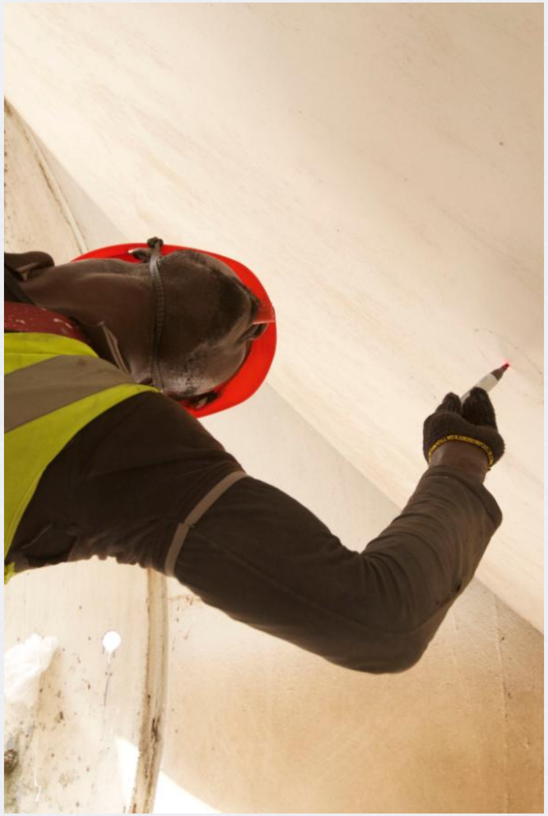
Quad legs - installation



Major Modifications

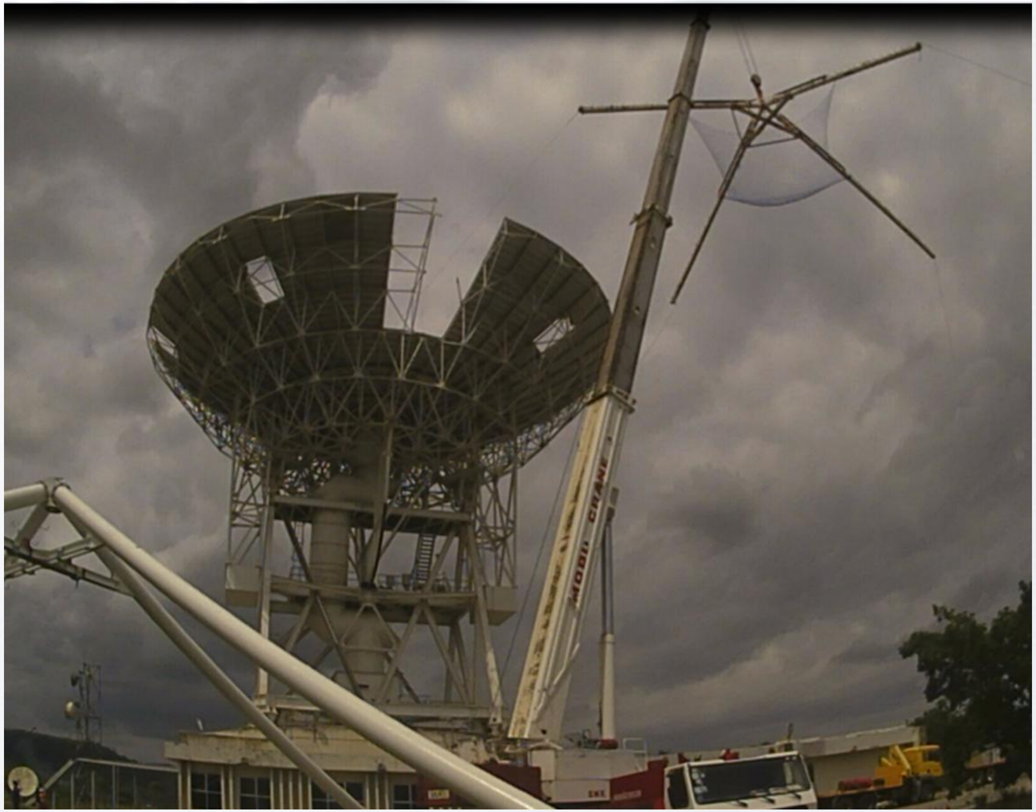
Quad legs - installation





Major Modifications

Quad legs - installation



Major Modifications

Quad legs - installation

Major Modifications

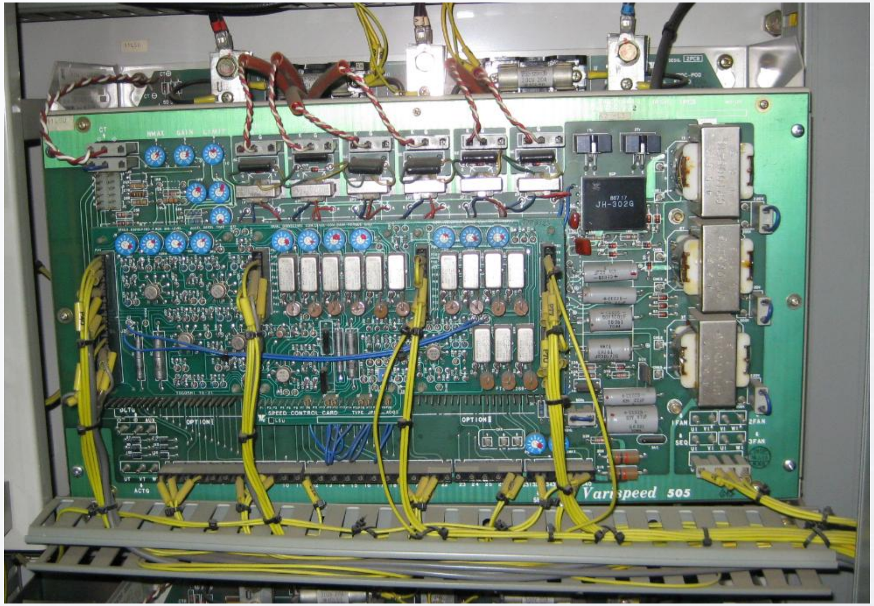
Quad legs - installation

Major Modifications

Quad legs - installation

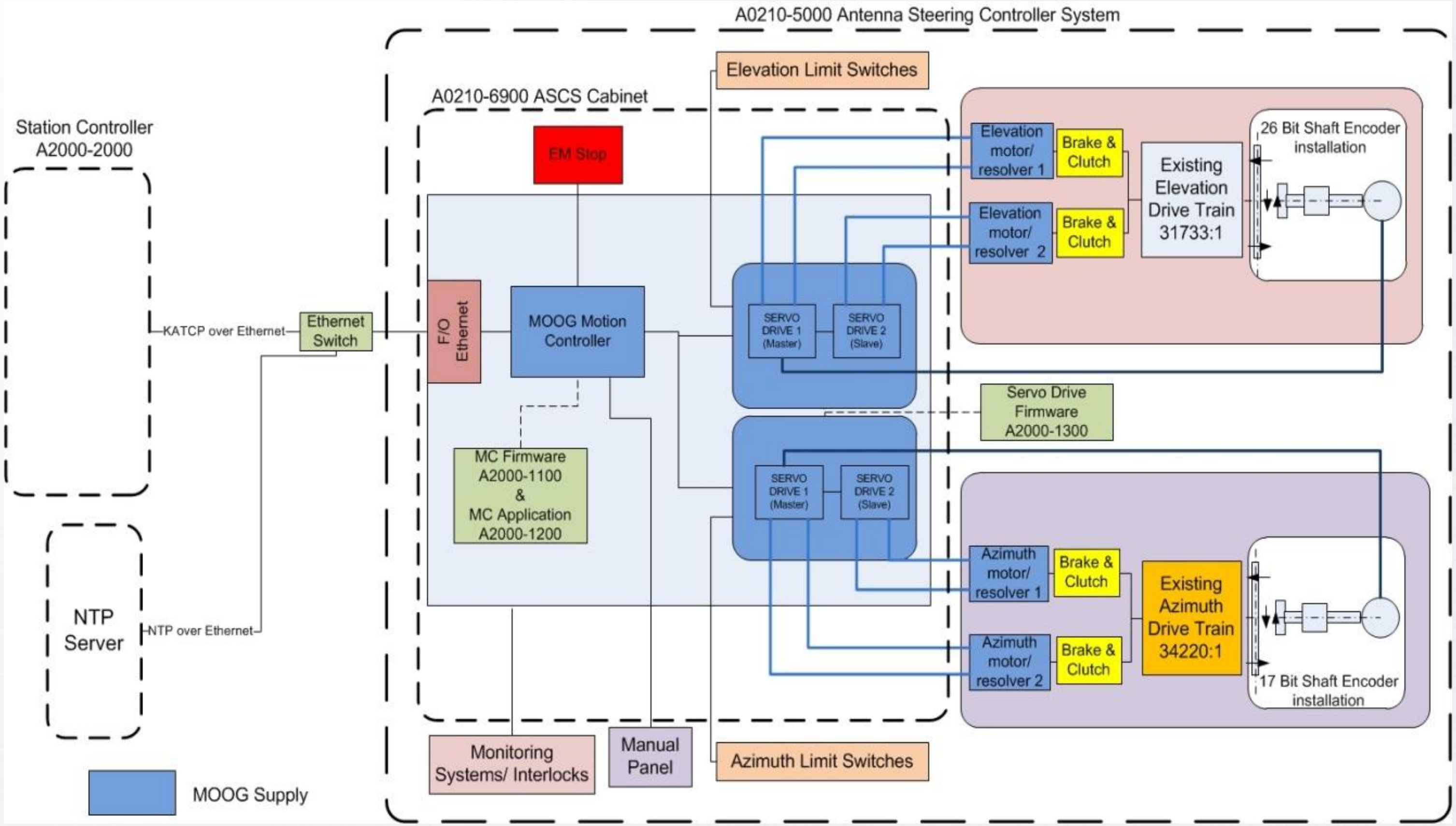
Major Modifications

Antenna Steering Controller System (ASCS) - Development



Major Modifications

ASCS - Development



Major Modifications - ASCS

Development outputs

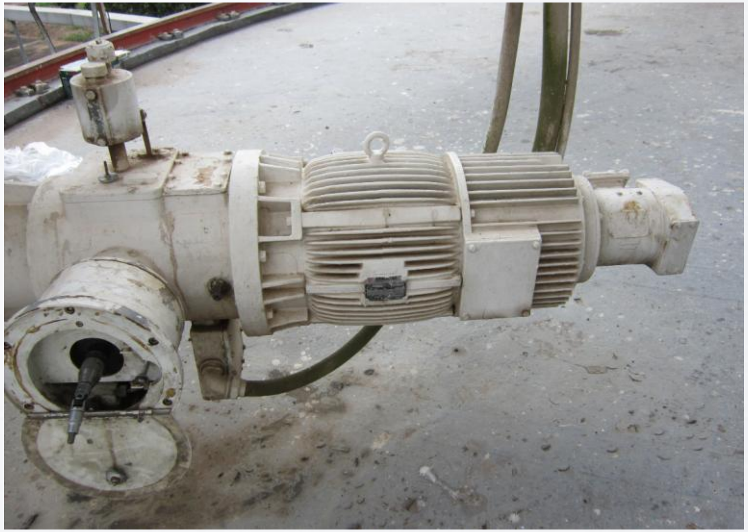
- Development of RFI shielded cabinet
- Development of control hardware architecture (Based on KAT-7 telescope)
- Development and commissioning of a system qualification test rig
- Software development and qualification
- System qualification, RFI measurements, packing and shipping to site
- On site integration and commissioning (safety and functionality testing)
- On site performance optimisation (control loops)

Major Modifications - ASCS

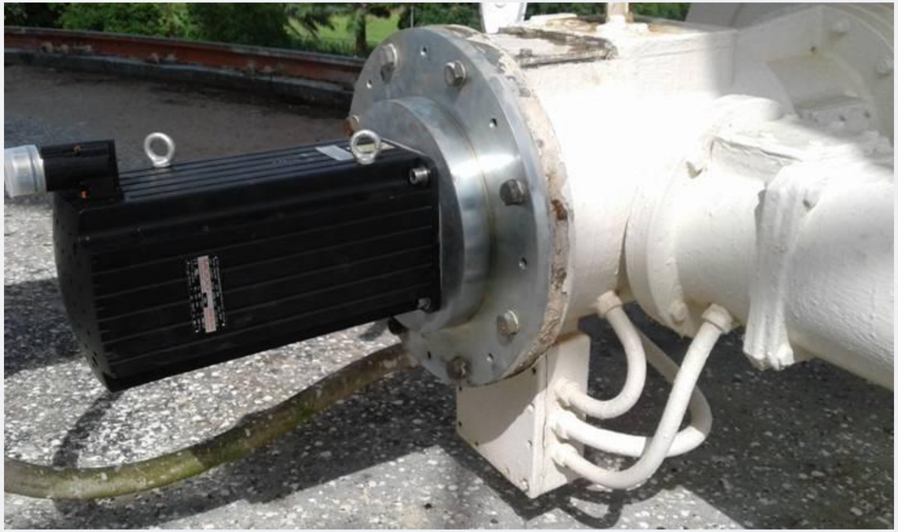
Test rig commissioning and qualification (Cape Town)

Major Modifications - ASCS

On site integration



Original DC motor – 450 kg



Servo motor – 50 kg

Performance predictions

Pointing error (Antenna Structure level)

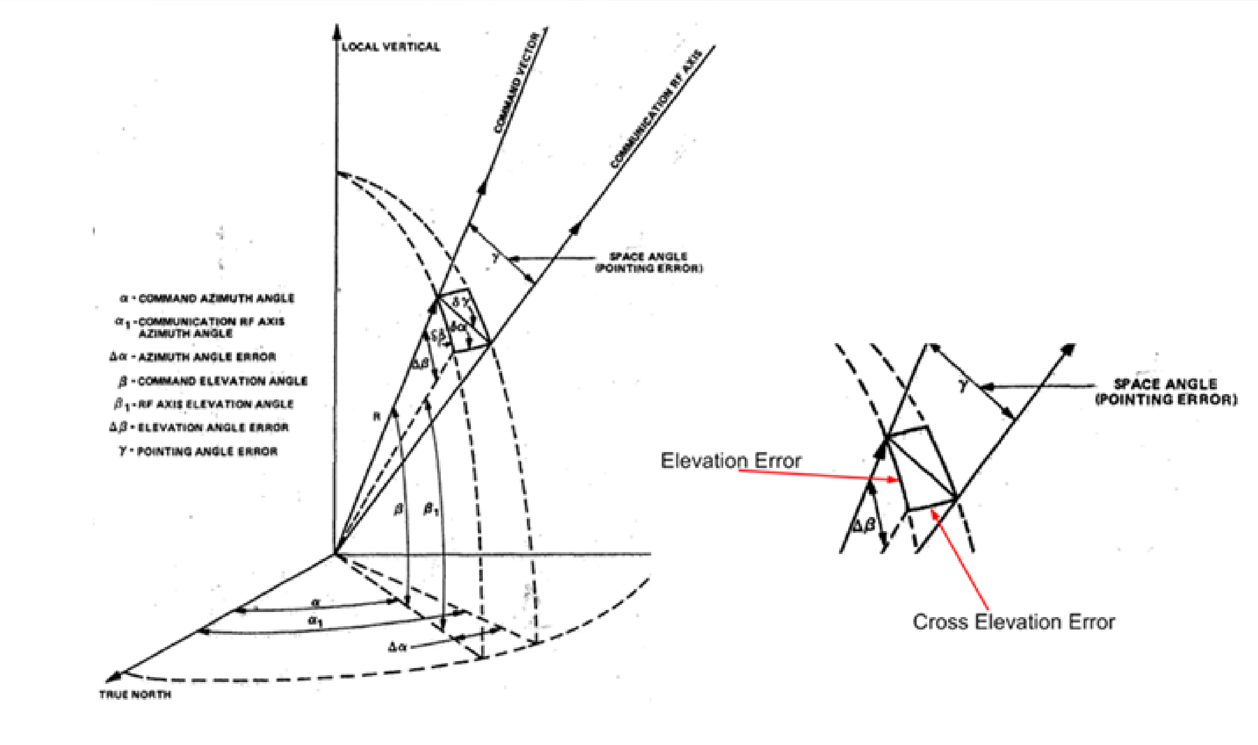


Figure 1: Pointing Error Definition

Performance predictions

Pointing error/Surface error

- Two types of error sources
  - Correlated errors: Errors which can be predicted by analysis and which are repeatable (e.g. gravity deflection)
  - Random errors: Errors which we only know the range (min, max) of (e.g. encoder accuracy)

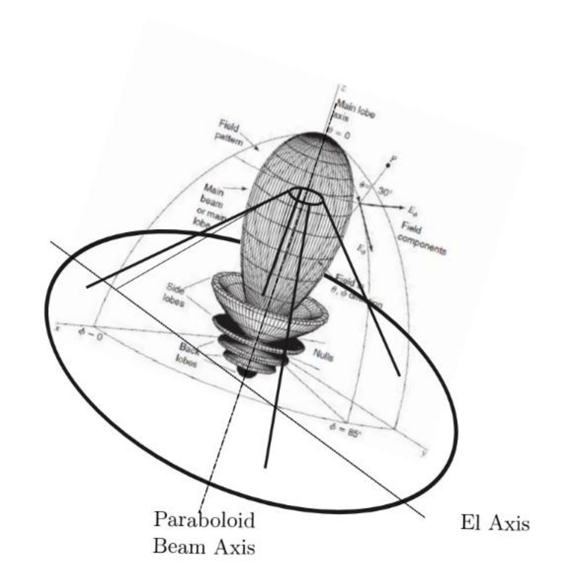
- Compensation
  - Repeatable errors can be compensated for (pointing model)
  - Some random errors can be eliminated /minimised(e.g. drive train backlash)

- Pointing error budget – summation of correlated and random errors based on analyses to predict subsystem error.

Performance predictions

Pointing error (Antenna Structure level)

- Initial operations will be at 5.6 – 6.7 GHz (HPBW = 0.0096 deg)

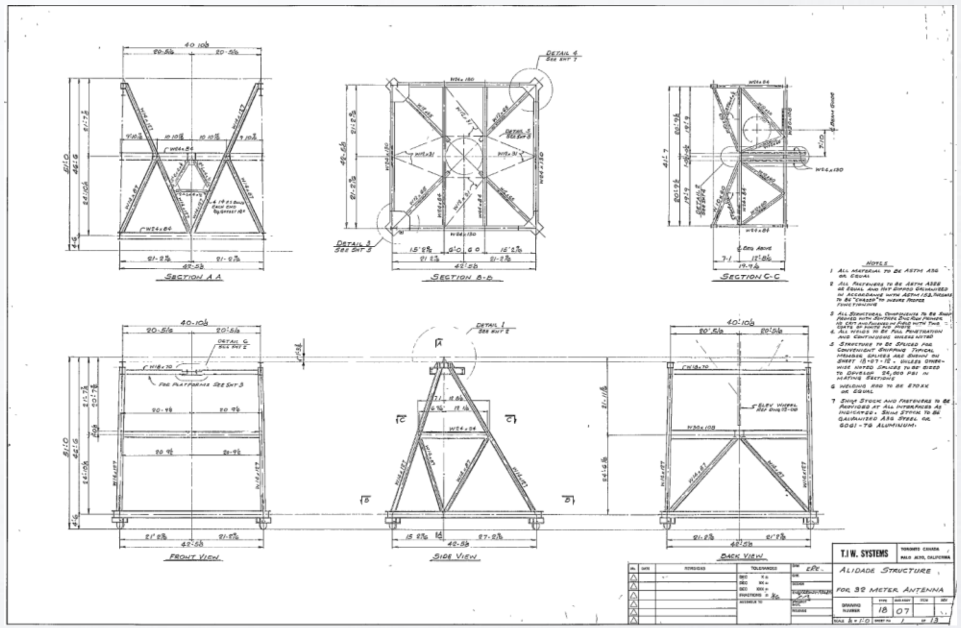


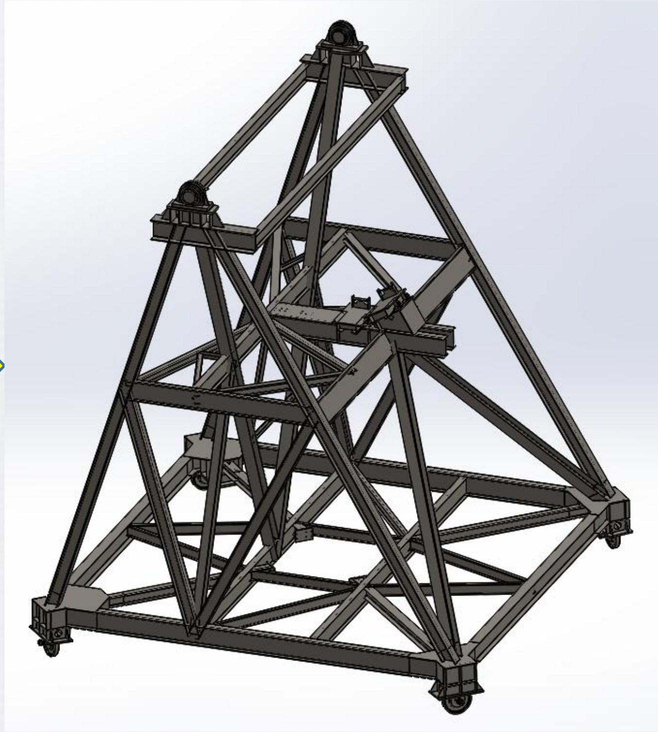
Pointing error budget				El = 0°, Az = 0°			
				Elevation Error		Cross Elevation Error	
Error definition	S	C	arcsec	deg		deg	
Correlated errors			W/O	W/O	W	W/O	W
RF axis collimation	RSS	C	14	0.0039	0.0004	0.0039	0.0004
Orthogonality refl/ EL axis	RSS	C	60			0.0167	0.0000
Orthogonality EL/AZ axis	RSS	C	10			0.0000	0.0000
Orthogonality AZ/track plane	RSS	C	7	0.002	0.001	0.002	0.001
Thermal (8K)	RSS		7.56	0.0021	0.0021	0.0021	0.0021
Gravity	A	C	5.76	0.0016	0.0002		
Wind deflection at 19 km/h (constant wind)	A		5.76	0.0016	0.0016		
Sum of Correlated errors/axis				0.0081	0.0041	0.0174	0.0024
Total correlated pointing error			Tot (W/O)	0.0191			
			Tot (W)	0.0047			
Random errors							
Drive train backlash	RMS	C	30	0.0083	0	0.0083	0
Encoder shaft deflection	RMS		1.1	0.00029	0.00029	0.0003	0.0003
Encoder accuracy	RMS		5	0.0014	0.0014	0.0014	0.0014
Azimuth Encoding Error (Wheelslip/Conc)	RMS	C	20•			0.0056	0.0044
Control loop	RMS		+/- 5	0.0010	0.0010	0.0014	0.0014
Sum of random errors				0.0043	0.0009	0.0046	0.0022
Total random pointing error			Tot (W/O)	0.0062			
			Tot (W)	0.0023			
Total Error (W/O)			91	0.0254			
Total Error (W)			25	0.0071			

Performance predictions

Pointing error (Antenna Structure level)

- Simulation – 3D CAD model from original 2D drawings (components, subassemblies)

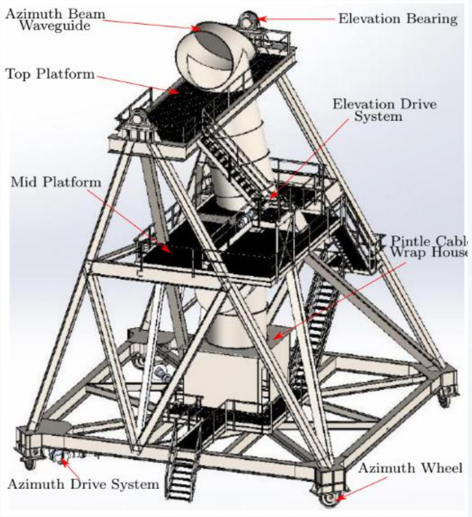


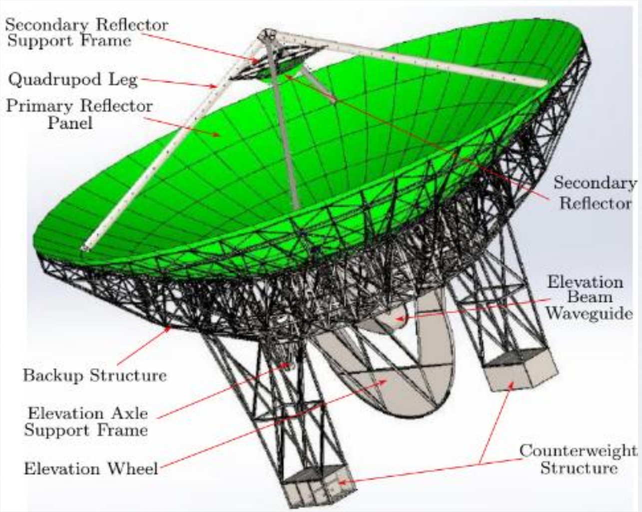


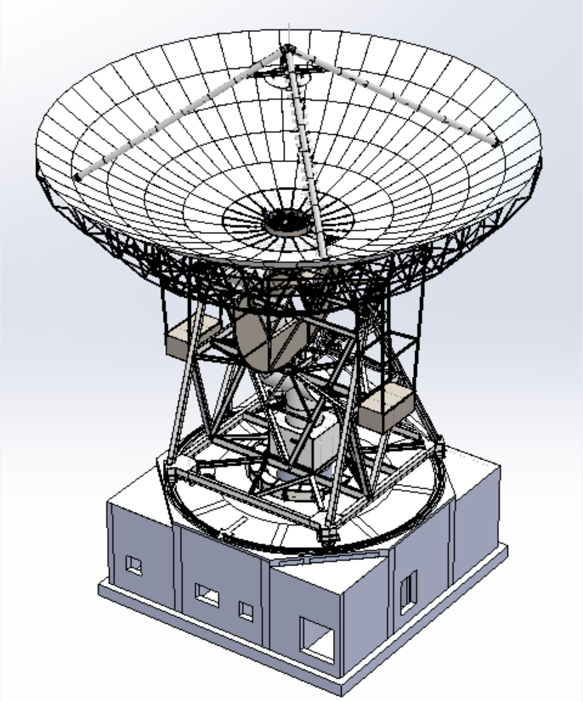
Performance predictions

Pointing error (Antenna Structure level)

- Simulation – 3D CAD model from original 2D drawings – (Sub-assemblies, Main Assembly)



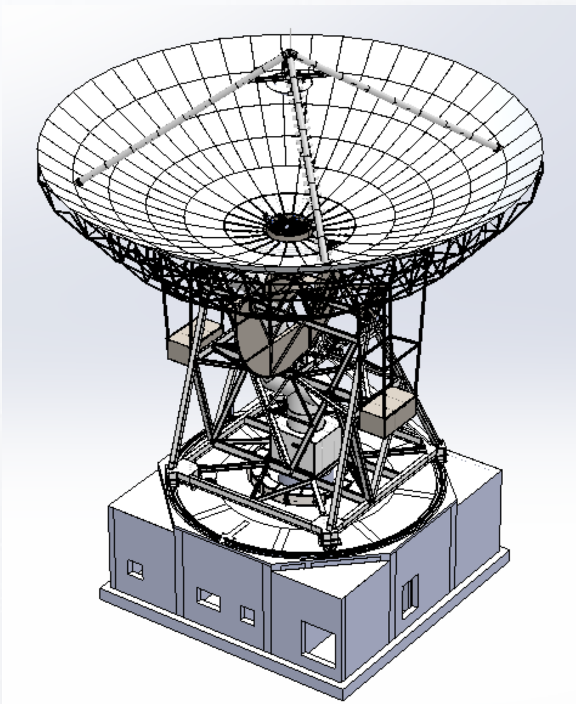


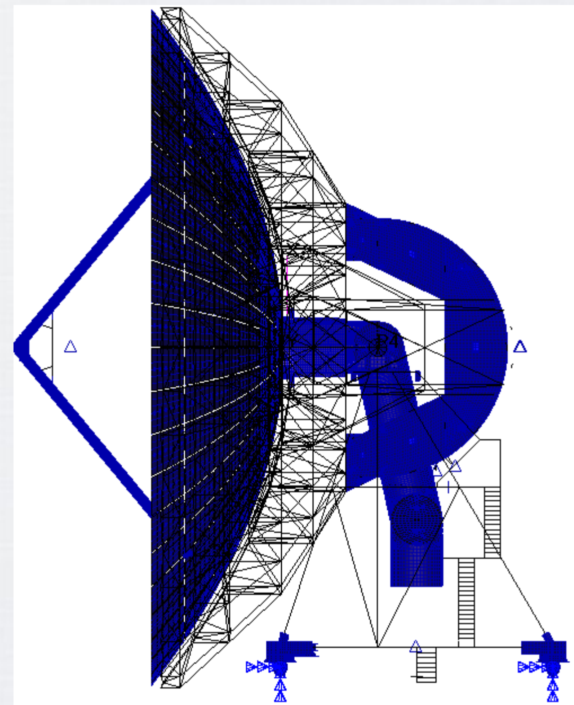


Performance predictions

Pointing error (Antenna Structure level)

- Simulation – 3D CAD model to Finite Element Model

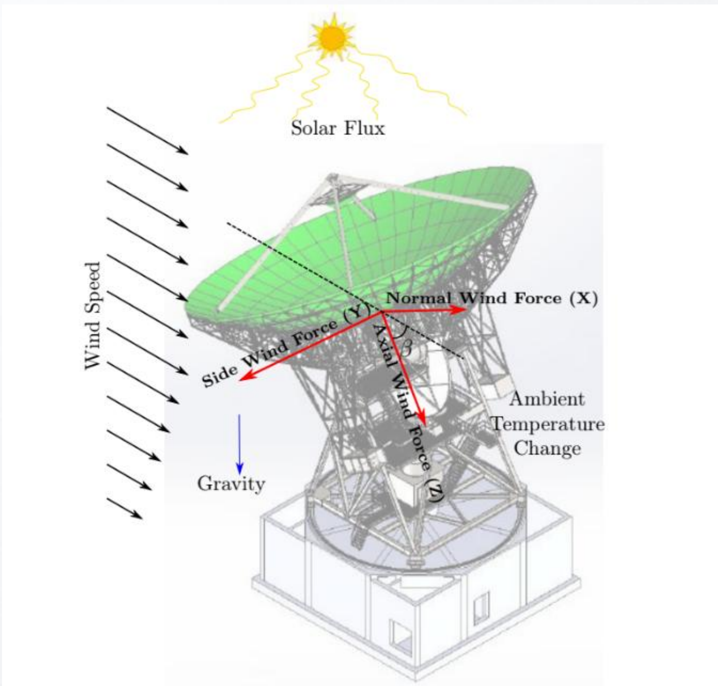


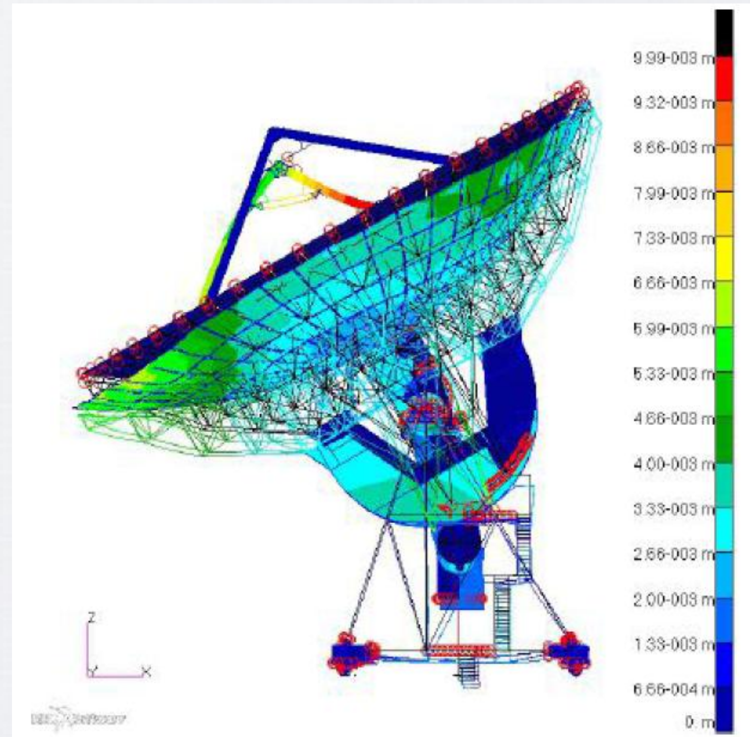


Performance predictions

Pointing error (Antenna Structure level)

- Simulation – Load Cases

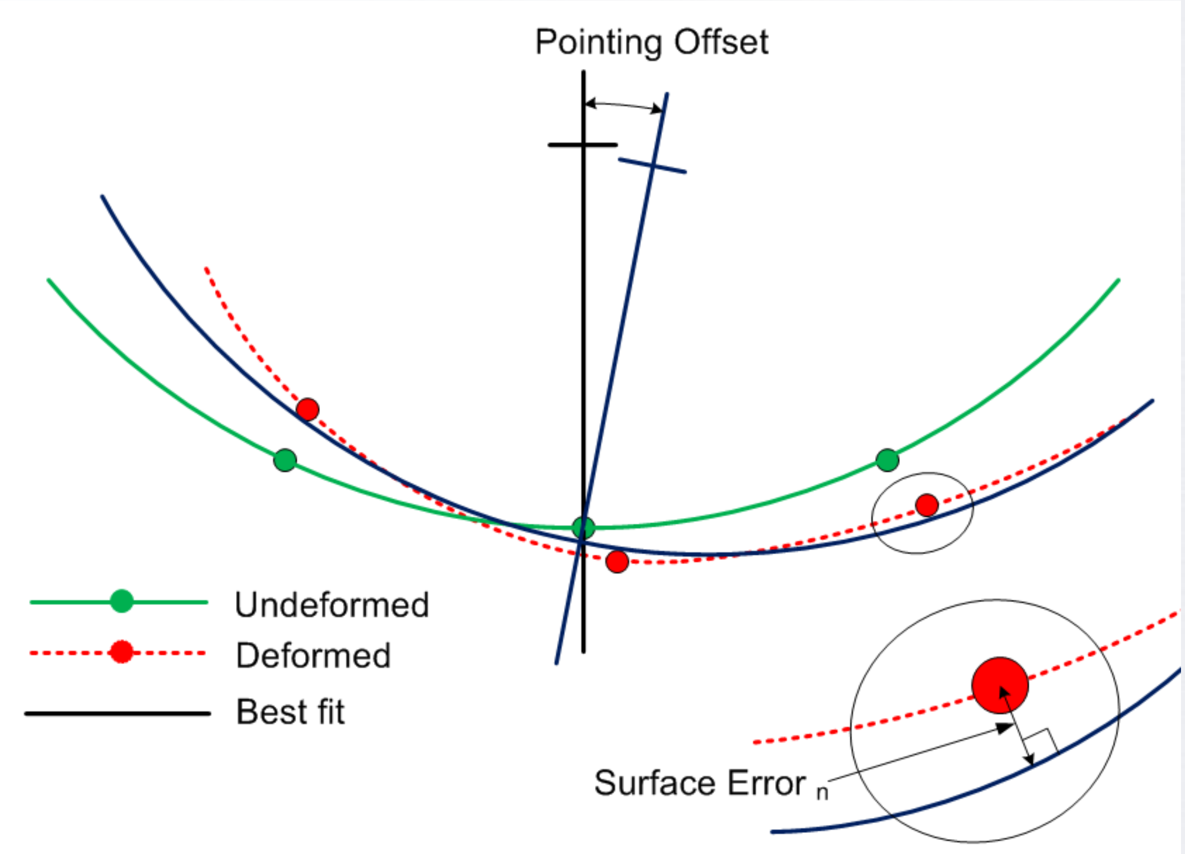




(d) Combined Load

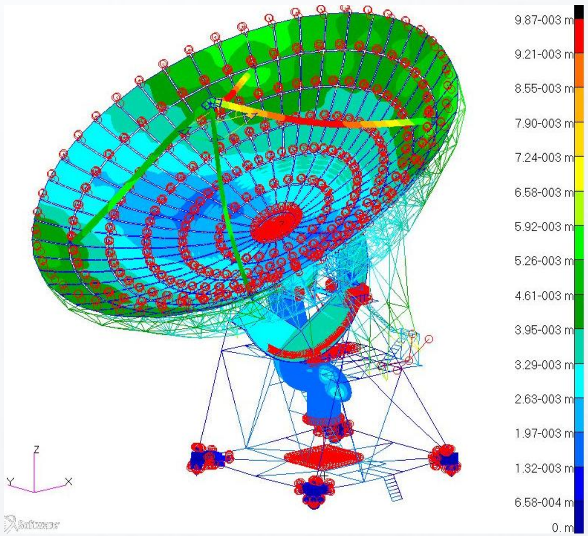
Performance predictions

Simulation : Deformation to Surface Error/Pointing Offset

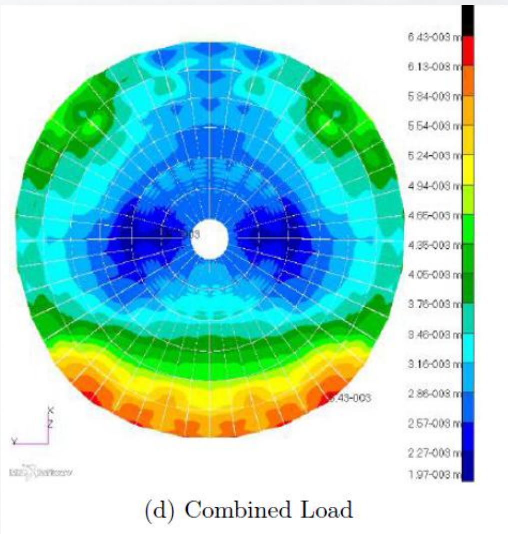


Performance predictions

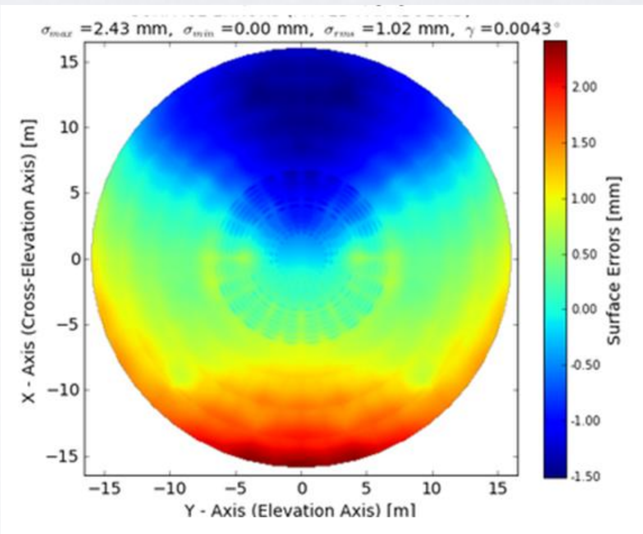
Simulation : Deformation to Surface Error



Global deformation



Dish deformation field



Surface error – best fit

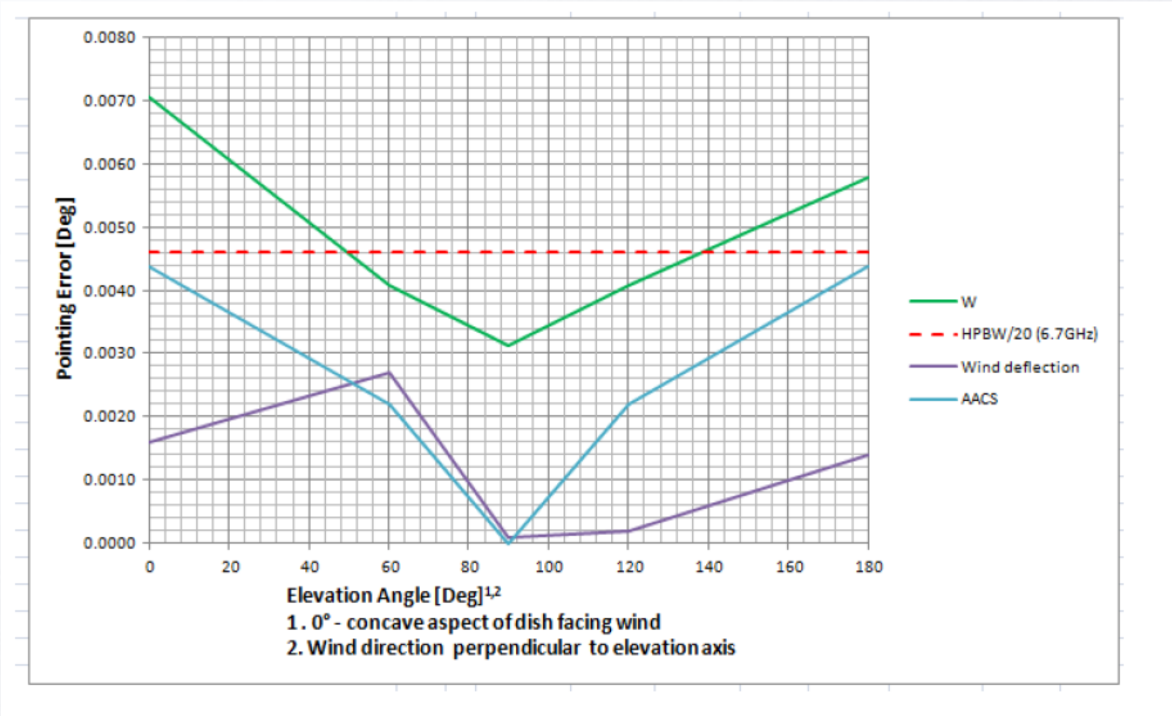
Performance predictions

Surface Error / Pointing Accuracy

- Surface Error – 1.02mm (Requirement is 2.5mm RMS)

Performance predictions

Surface Error / Pointing Accuracy

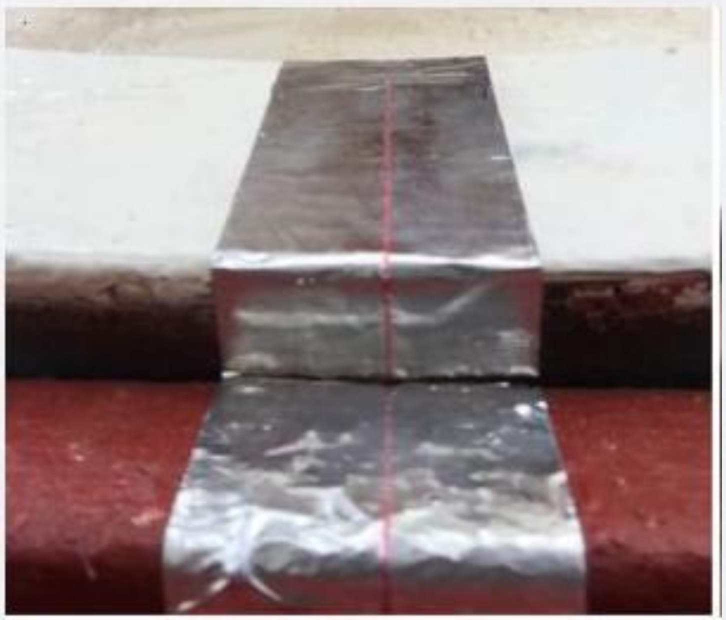


Current Issues

Azimuth encoding error – “Wheel slip”

- Encoder mounted to shaft of idler (non-driven) wheel

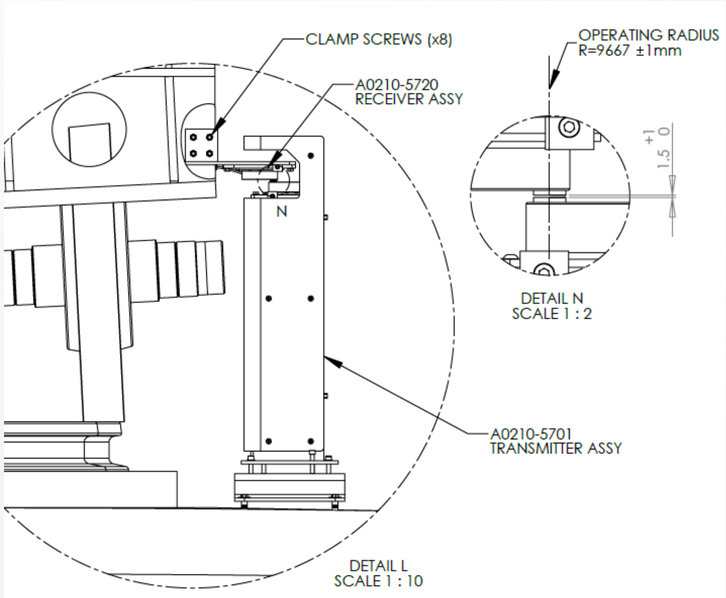
- Wheel-slip due to wheel alignment error

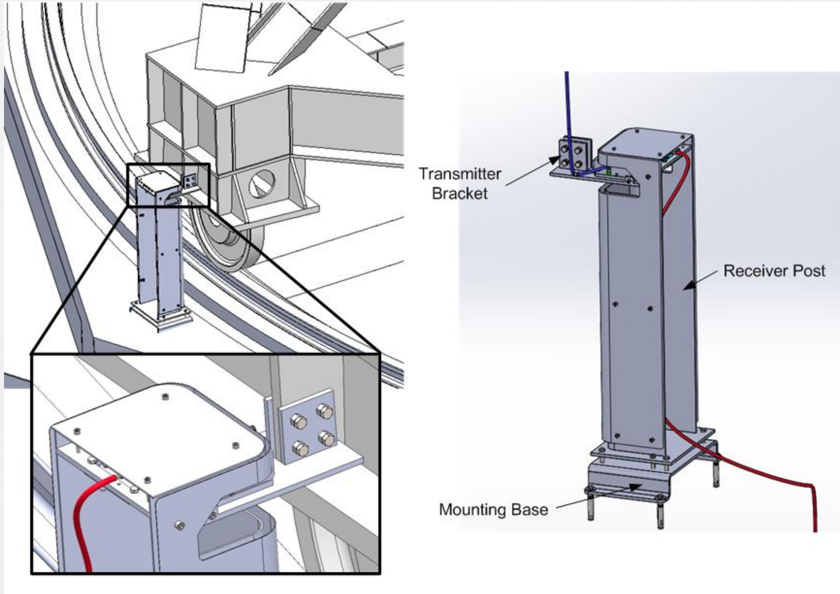


Current Issues

Azimuth encoding error – “Wheel slip”

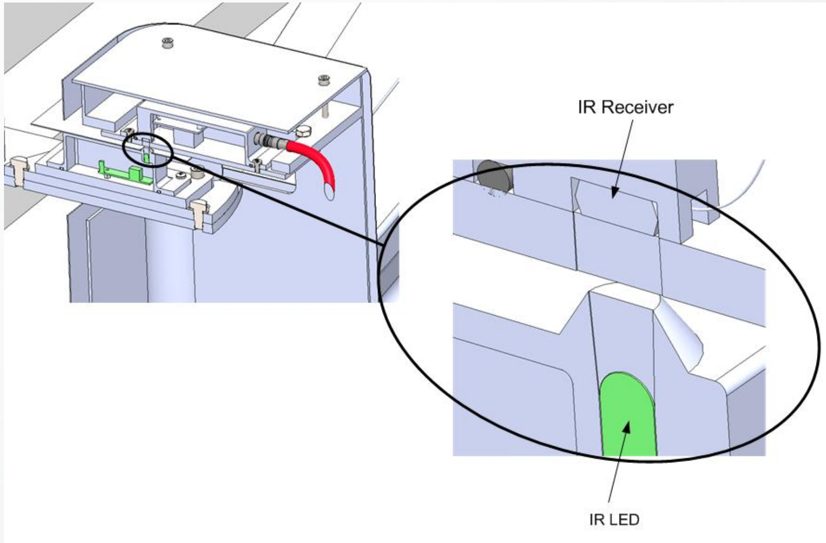
- Intermediate fix : Infrared reset switch to reset cumulative error once per day

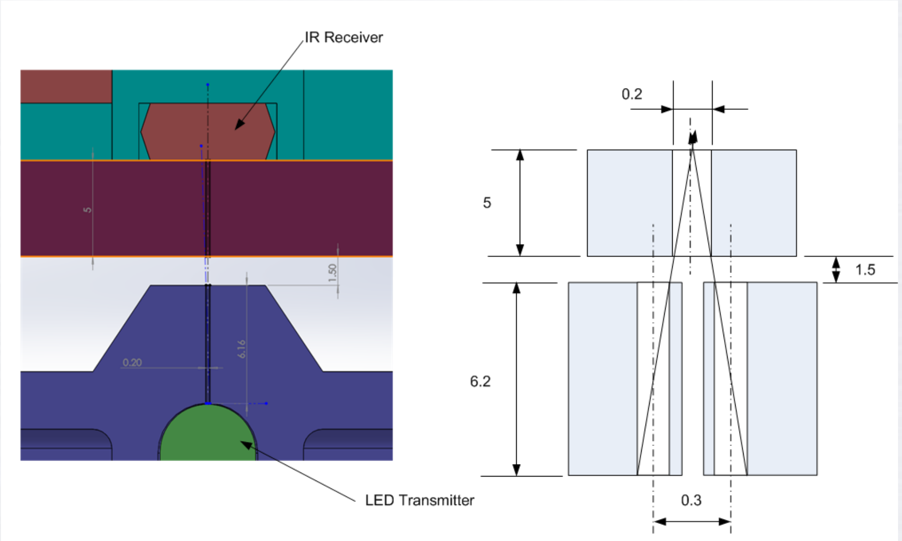




Current Issues

Azimuth encoding error – “Wheel slip”

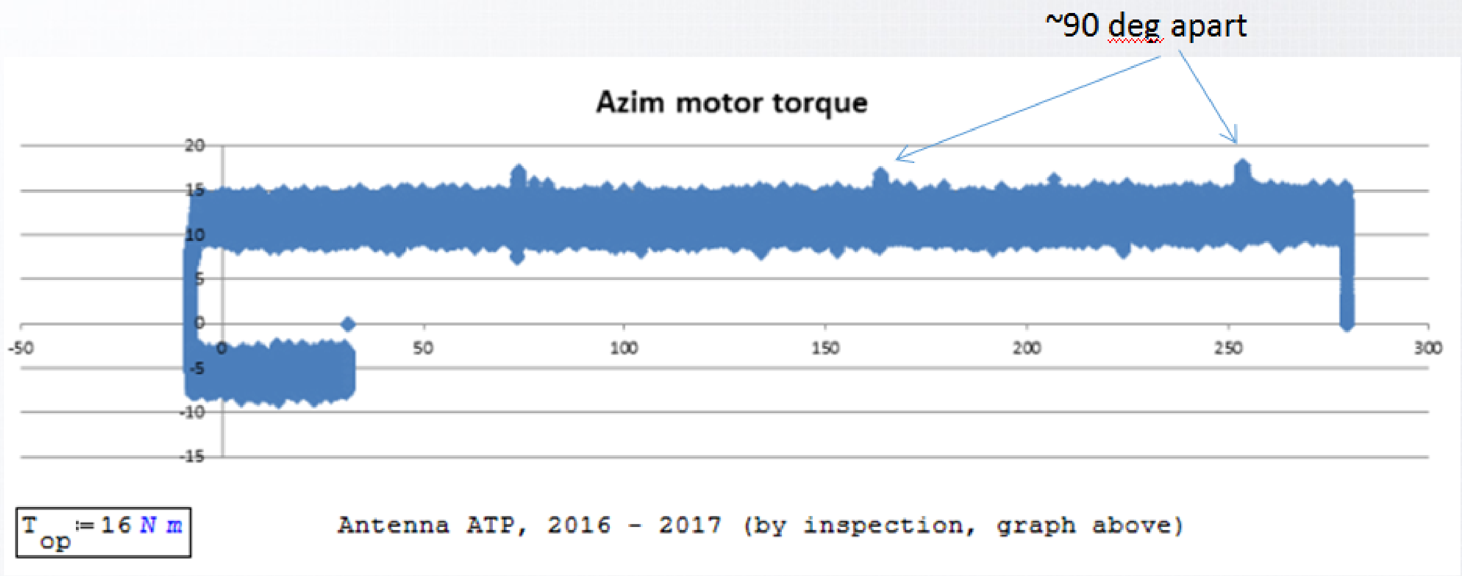




	Error Budget		
	Wheelslip reset system	deg	
	Switch Range	0.001	0.2mm slots
	Delay	0.003	(10 ms at 0.3 deg/s) x 2
	Post angular position	0.00140	Theodolite Accuracy
	Post thermal distortion	0.001	Delta T = 20 deg C
RMS	Residual error	0.0018	

Current Issues

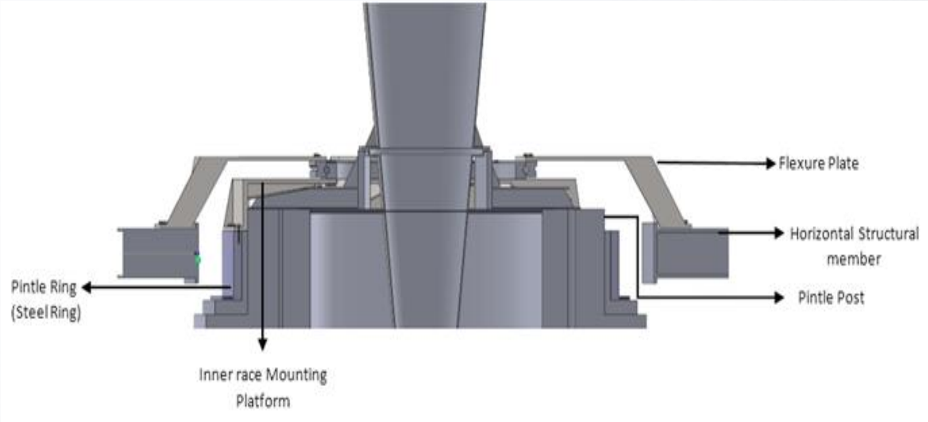
Stiction points – azimuth rotation

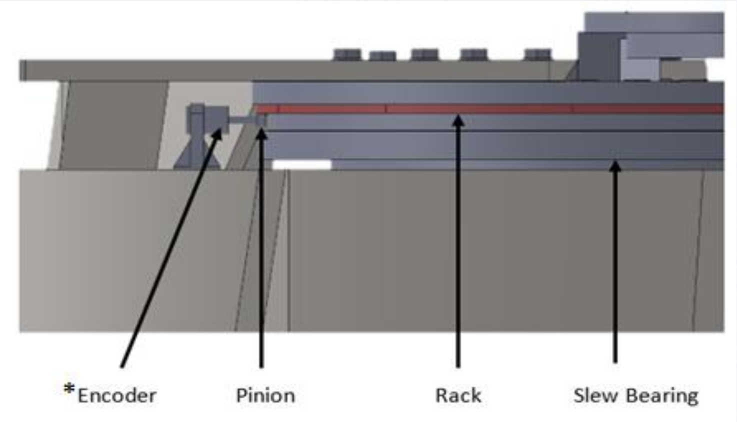


Current Issues

Azimuth encoding error/ Stiction points

- Long Term Solution – 360 deg bearing / gear driven encoder

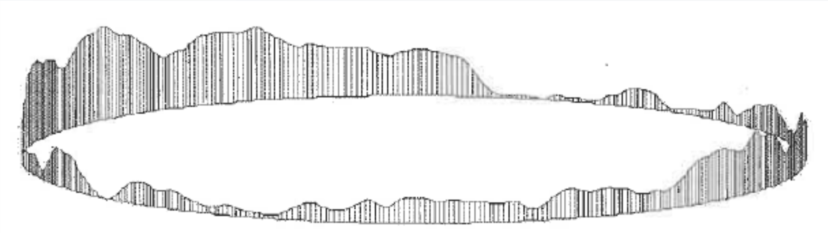




Currently Developing

Track Level Compensation

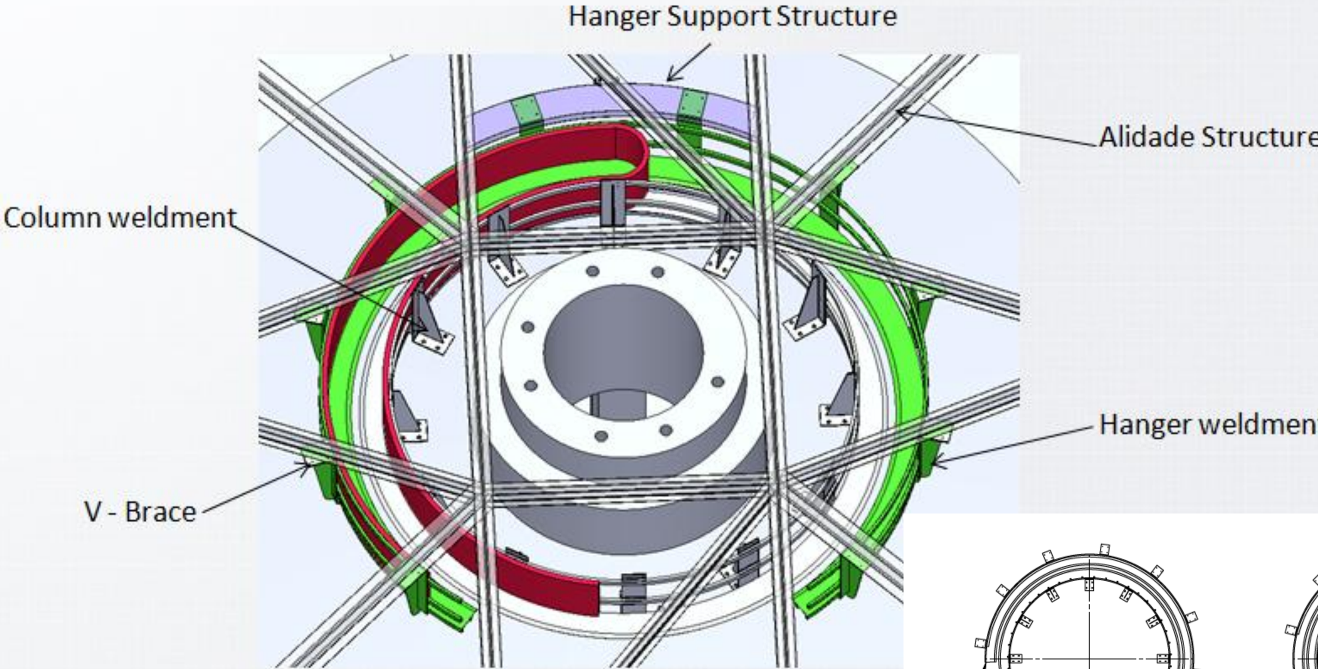
- Ghana: Track installed to within ±0.2 mm (from ATR) – current track condition unknown.
- In Comparison: 34-m DSN antenna ±0.6 mm (measured with TLC system) [1]

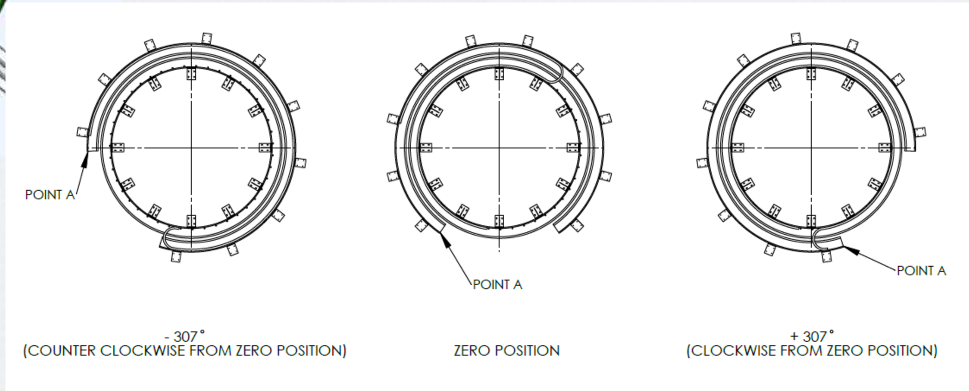


	Elevation error	Cross-Elevation Error
Without TLC	7.5 mdeg	20.4 mdeg
With TLC	1.2 mdeg	2.2
Improvement	**6.3 mdeg**	**18.2***

- *For the DSN antenna pure Z-rotation from the TLC was disregard as the Az encoder is mounted directly on the Z-axis and sufficiently compensates for pure Z-rotation errors.

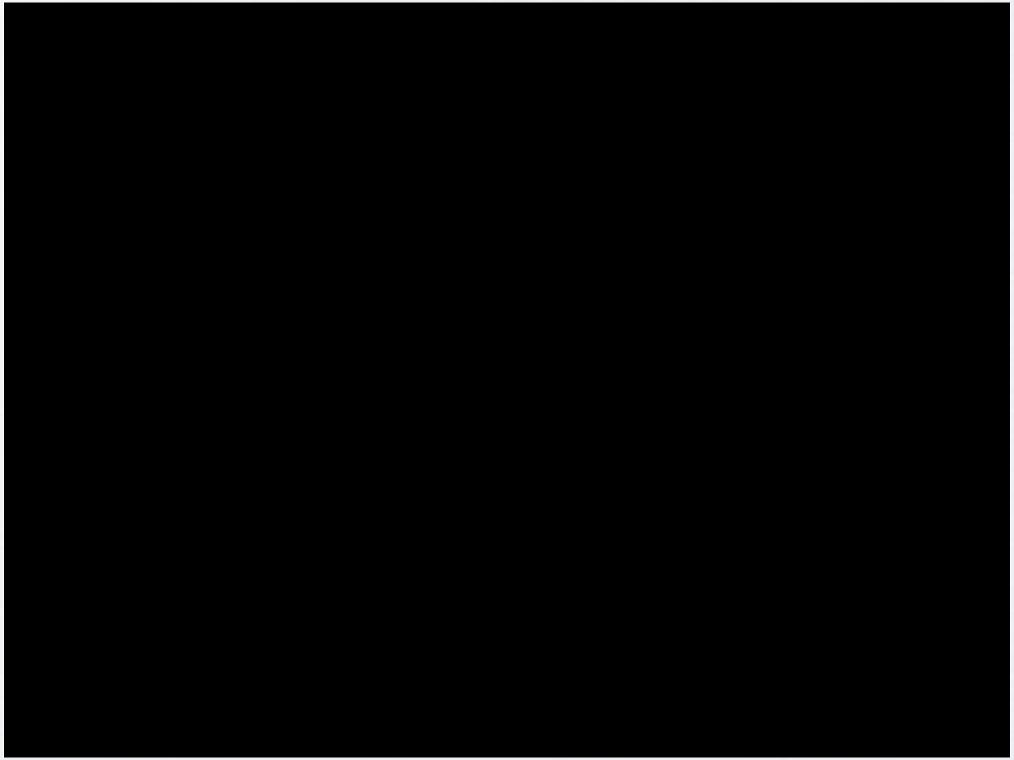
Currently Developing





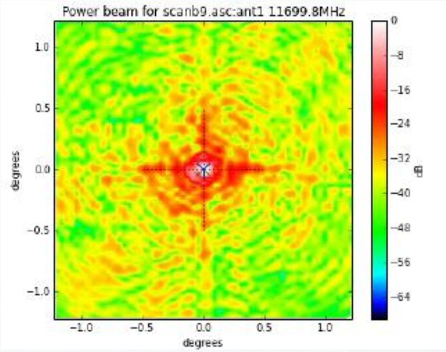
Currently Developing

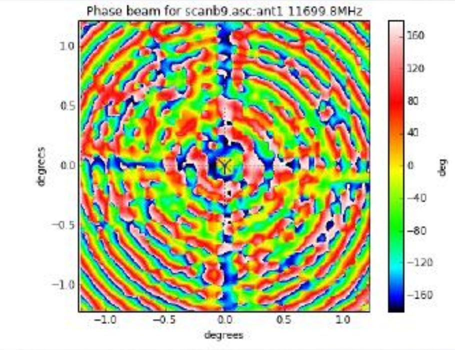
+/-305° Cable Wrap Testing Rig – Cape Town

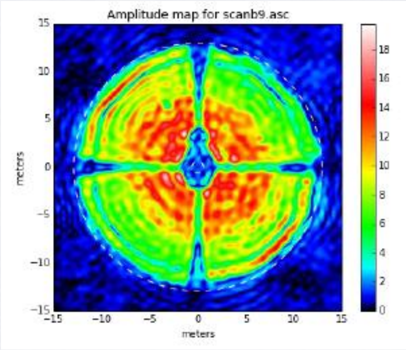


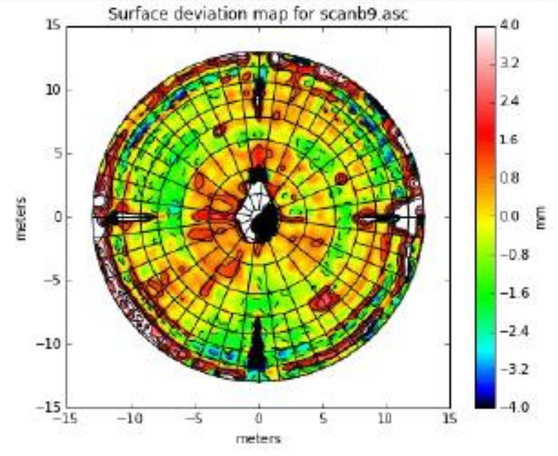
Currently Developing

Microwave Holography

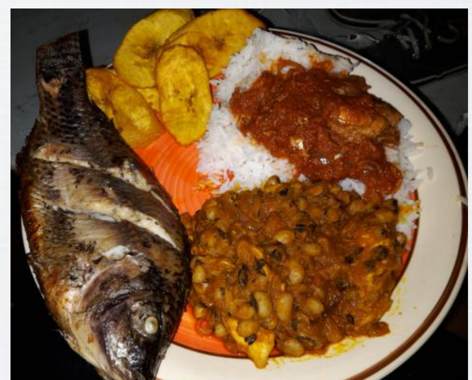








Thank you - Questions?



SARAO, a business unit of the National Research Foundation.

The South African Radio Astronomy Observatory (SARAO) spearheads South Africa's activities in the Square Kilometre Array Radio Telescope, commonly known as the SKA, in engineering, science and construction. SARAO is a National Facility managed by the National Research Foundation and incorporates radio astronomy instruments and programmes such as the MeerKAT and KAT-7 telescopes in the Karoo, the Hartebeesthoek Radio Astronomy Observatory (HartRAO) in Gauteng, the African Very Long Baseline Interferometry (AVN) programme in nine African countries as well as the associated human capital development and commercialisation endeavours.

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