SKA DISH VERIFICATION ANTENNA DVA-1, DESIGN & FABRICATION

NGVLA Meeting, Caltech, Pasadena CA

April 8, 2015

Matt Fleming, presenter, on behalf of many contributors.

Experience on the following projects

UC Berkeley, --- BIMA, CARMA, ATA, US-SKA-TDP

Minex Engineering, ---- ATA fab & SKA-DVA-1 fab

The Object of Today's Talk

SKA Dish Verification Antenna 1, known as DVA-1

DVA-1 Antenna Design Team

US SKA Consortium, NSF Technology Development Program

Cornel University, Ithaca
- Jim Cordes
- Lynn Baker
- German Cortes

University of California, Berkeley
- Jack Welch
- Matt Fleming
- Dave DeBoer

Jet Propulsion Lab
- Sandy Weinreb
- Bill Imbraile

Consulting
- Roger Schultz

National Research Council Canada Hertzberg Institute for Astrophysics CART Program

Composite Applications for Radio Astronomy

Dominion Radio Obs. Penticton CART
- Gary Hovey
- Gordon Lacey
- Bruce Veidt
- Tony Willis
- Richard Hellyer

Hertzberg Inst, Victoria
- Joeleff Fitzsimmons
- Peter Byrnes
- Kei Szeto

SKA Office, SPDO
- Peter Dewdney
- Neil Roddis

CART Program

DVA-1 Fabrication & Funding

TDP remaining funds
NSF

SKA SPDO
funds

National Research Council Canada
Hertzberg Institute for Astrophysics

Mount Drives & Steel Structures
- Minex Engineering Corp.
- Wilcox Machine
- Harrison Industrial
- Glen Crete Fabrication

Majority Fabrication Funding Through NRC

Reflector Surfaces & Support Structures
- Dominion Radio Obs. CART Team

Foundation & Site Infrastructure
- Penticton Contractors

Composite Tubes & Fittings
- Profile Composites

Outline for this Presentation

Antenna design opportunities with a large array.

Discussion of SKA Dish specs & design drivers.

Optics design. (feed dependent)

Structural design. (basic approach)

Reflector design & fabrication. (new technology from NRC)

Mount design & fabrication. (low maintenance machinery)

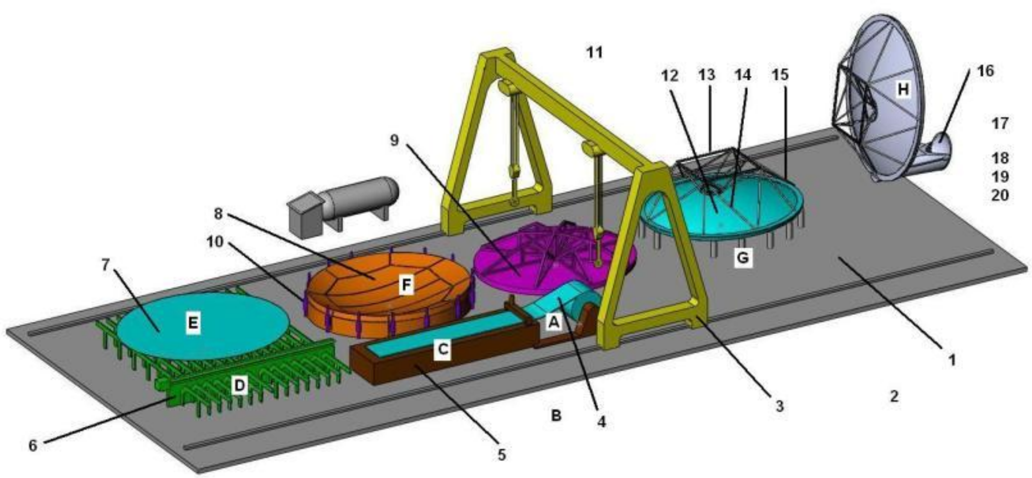
Installation.

Testing.

Comments for future antennas.

Design Opportunities with High Volume Antenna Production.

Engineering costs can be amortized over many units.
Complex tooling can be easily justified.
Custom designs for higher reliability are well justified.
Designs with parts that fit shipping containers allows more sources.
Factory assembly and delivery of pre-tested systems is justified.
On site fabrication can use more complex processes.



Dish Specifications & Design Drivers.

Low Cost and High Performance

Searching for the right compromise.

A discussion of what the SKA wrestled with.

Strawman Design

Science Requirements and Project Cost Tradeoffs

Array Number & Size of Antennas (Less is More ?)
This discussion is critical during early array design.

Two truths always seem to compete

Truth 1: A smaller number of large antennas is better.
Truth 2: A lager number of small antennas is better.

This comes from different interpretations of the following costs:

Antennas, Feeds, Baselines, Infrastructure, Maintenance.

SKA worked hard on this costing function.

Array Design Tradeoffs

Jack Welch
Peter Dewdney

1. For an array in survey observation: Truth 2, small dishes.

   speed & sensitivity is a function of ND (where N = number, D = diameter)

2. For an array in point source observation: Truth 1, lager dishes.

   speed & sensitivity is a function of ND^2

3. Larger antennas require better surface accuracy & pointing, but make
   . success more difficult, therefore Truth 2, small dishes.

4. Cost of Feeds, constant but usually high, truth 1, large dishes.

   (spend money on research , development & engineering)

5. Cost of Infrastructure, therefore: Truth 1, large dishes.

6. Cost from number of baselines: Truth 1, large dishes.(computing & Moore's Law)

7. Cost of Maintenance, Truth 1, larger dishes, but really "proven prototypes of good design is the dominant factor".

Antenna Design Tradeoffs

What feed systems will be used.

Symmetric vs offset (lowest frequency)

Offset high vs offset low. (maybe feed spillover dependant)

Shaped reflectors vs true conic sections.

Paneled reflector vs Single Skin.

Composite vs metal surfaces

Stow position & survival position.

Close spacing short baseline requirements.

Spillover.

SKA Antenna Design Drivers

1 Low cost antenna at high volume. (very system driven)
   (low cost materials, low mass design, low fab labor)

DVA-1 min cost & mass, add material to meet specs.

2 Low cost operation for a 30 year life.
   (very few maintenance visits 60 month interval)(get it right or pay)

3 Allow operational modes to match environment.
   (specifications for operation in several environments, high freq on a calm night)

3 Frequency range of 0.5 to 10 GHz.
   (4.0m Gregorian secondary) (favors offset)

Performance vs Cost Tradeoffs

4 Large & flexible feed area. WBSPF & PAF
   (several wide band single pixel feeds & possibly a phased array feed) (favors offset)

5 Excellent Ae / Tsys.
   (accurate surfaces, controlled spillover, low diffraction) (favors offset)

6 Exceptional dynamic range.
   (not just accuracy, but very “stable” surfaces, very “consistent” pointing,)

Strawman Spec Compare

	DVA-1	NGVLA		
Dia	15	18	m	1.20
Area	177	254	sq-m	1.44
Frequency Max	10	100	GHz	
Surface rms	30	16		N
	1.00	0.188	mm	W / N
Pointing rms	50	10		N
	10.1	4.2	arc-sec	B / N

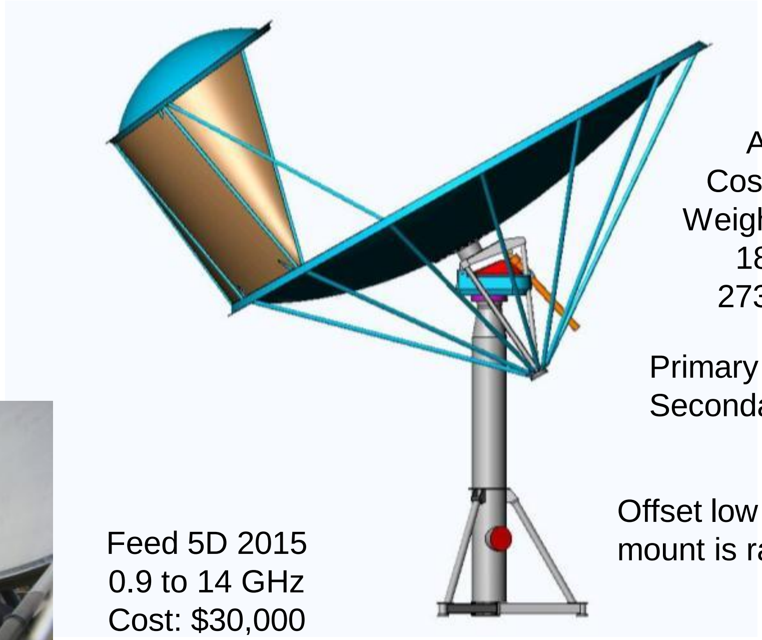
Precision pointing at 10 arcsec means
edge movement of 0.74mm (0.029”) across 15m.

Building on the ATA experience.

•A large number of low cost antennas with a single wide band feed.
•Hydroformed aluminum thin primary supported at the rim with flex center.
•Wind & gravity moment loads are reduced with Az & El near the shell center.
•A compact close nested turnhead contains all the precision machining.
•Stow at low elevation and windsock as needed and allow drives to yield.

Feed 4C 2009
0.5 to 10 GHz
Cost:
Weight:

Feed 5D 2015
0.9 to 14 GHz
Cost: $30,000
Weight: 70 lbs



Antenna
Cost: $80,000
Weight: 4,350 lbs
18.39 $/lb
2737 $/sq-m

Primary 6.1 x 7.0m
Secondary 2.4m

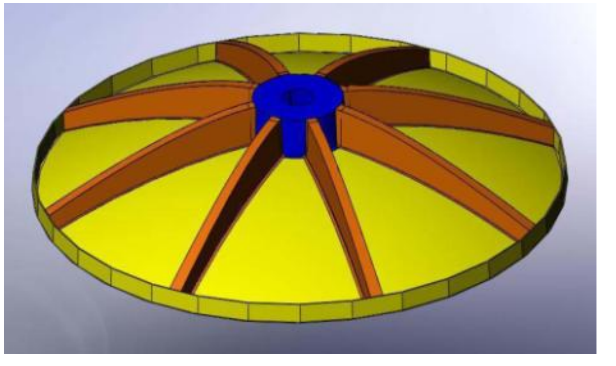
Offset low therefore mount is rather tall.

Collaboration US-TDP & NRC-CART

- TDP, for reflectors 6 to 12m, hydroforming was projected to be problematic.
- CART, for reflectors at 10m and up composite was looking promising if thiin.
- Composite technology developing in Canada is a perfect solution.
- Work began to apply composite technology to a thin shell antenna.
- Some of the same manufacturing issues are present, but better in composite.

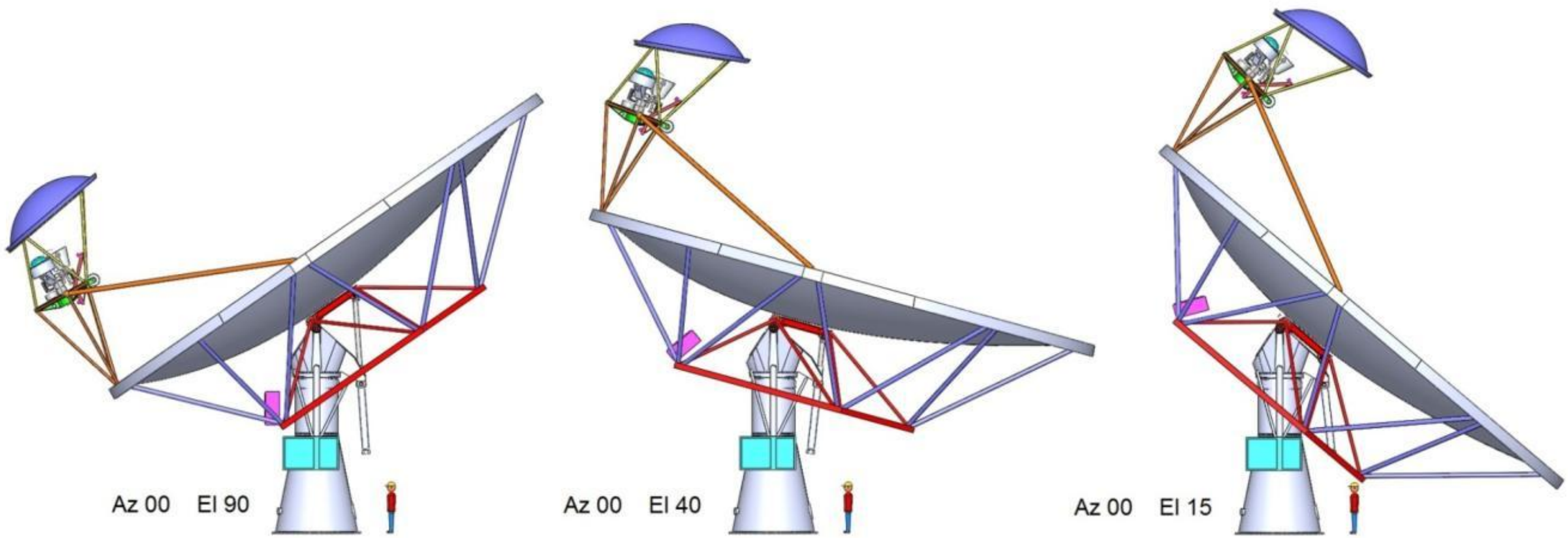
Also South Africa

Prototype 10m complete.
Symmetric with Core, Beams & Hub



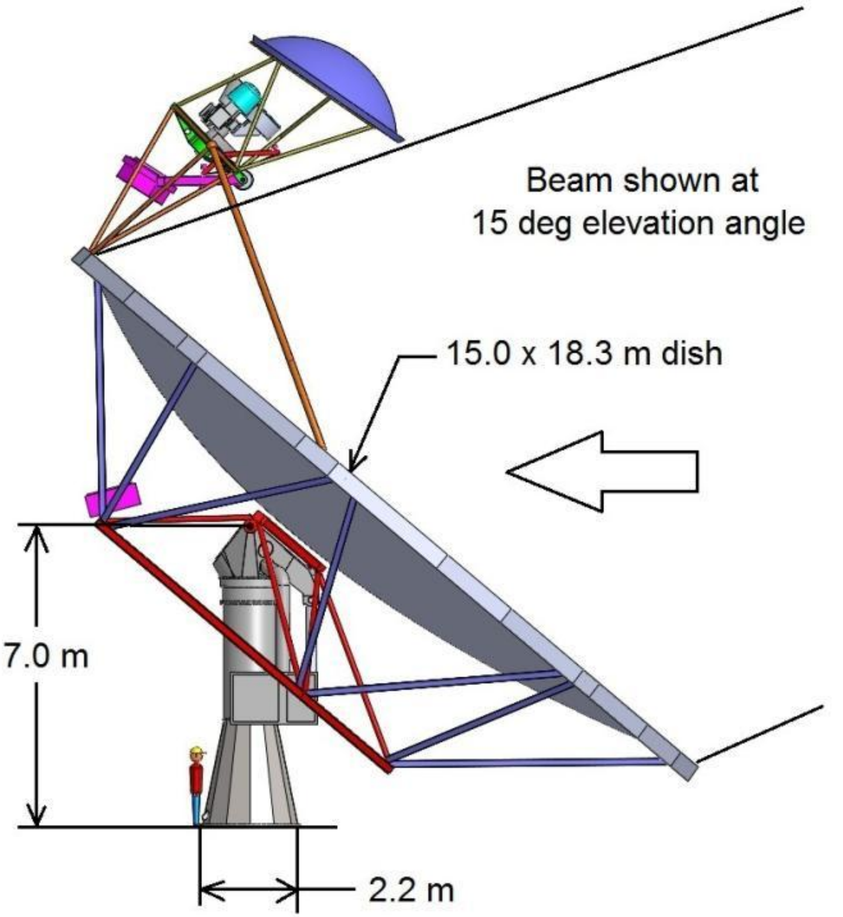
DRAO = Dominion Radio Astronomical Observatory
CART = Composite Application Radio Telescope

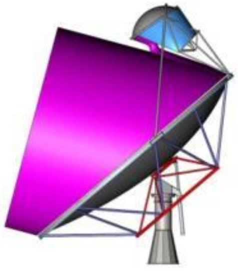
Antenna Several Positions



Zenith position Stow Position Low Position

Why This Optics Choice

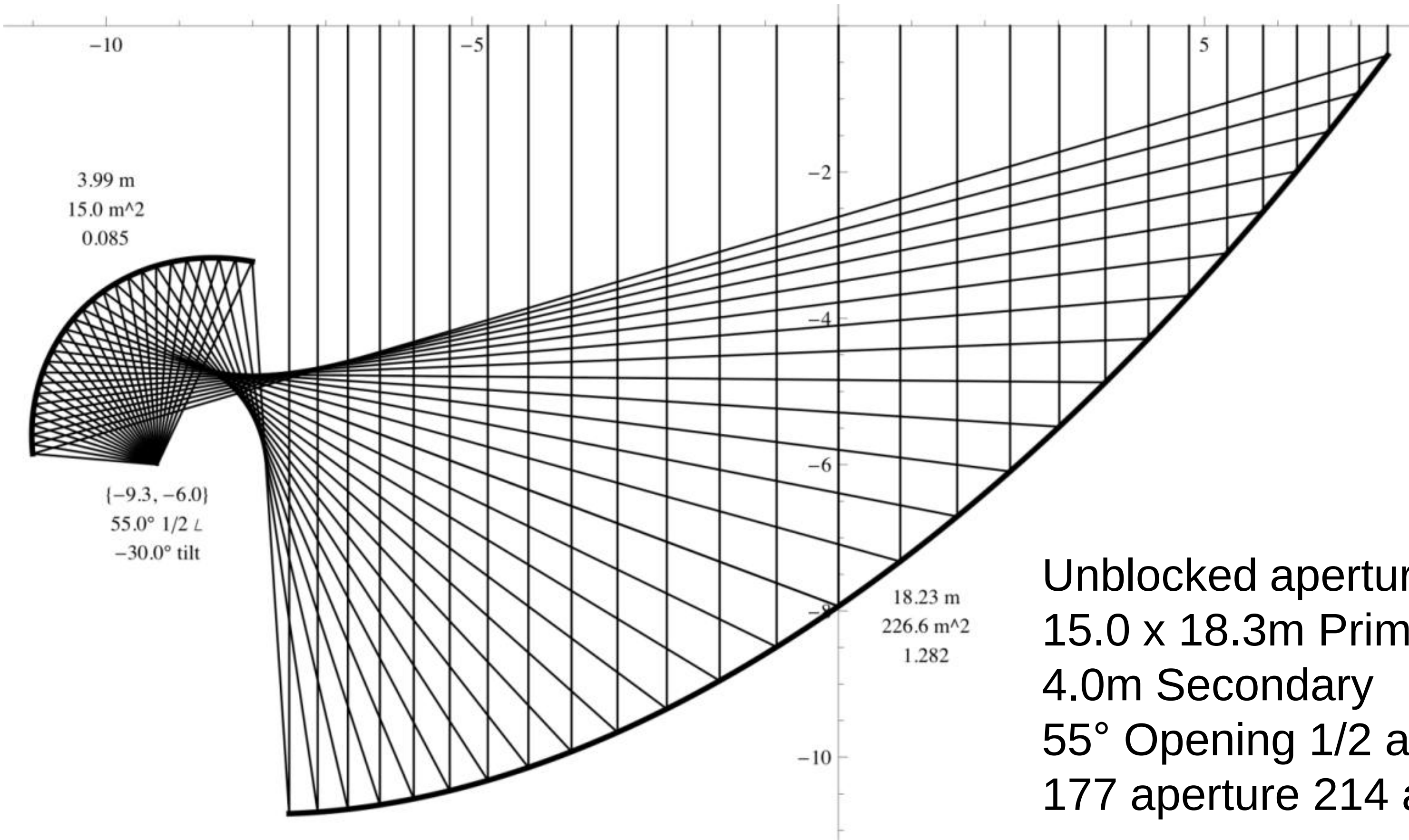




Optics Design

Ray trace for shaped optics

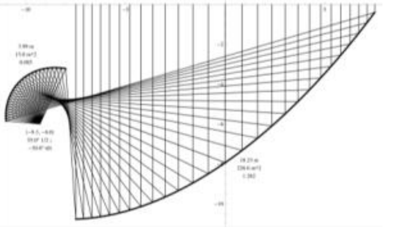
Extensive work by Lynn Baker,
German Cortes & Bill Imbriale



Unblocked aperture
15.0 x 18.3m Primary
4.0m Secondary
55° Opening 1/2 angle
177 aperture 214 area 22%

Optics Design

Features of the design

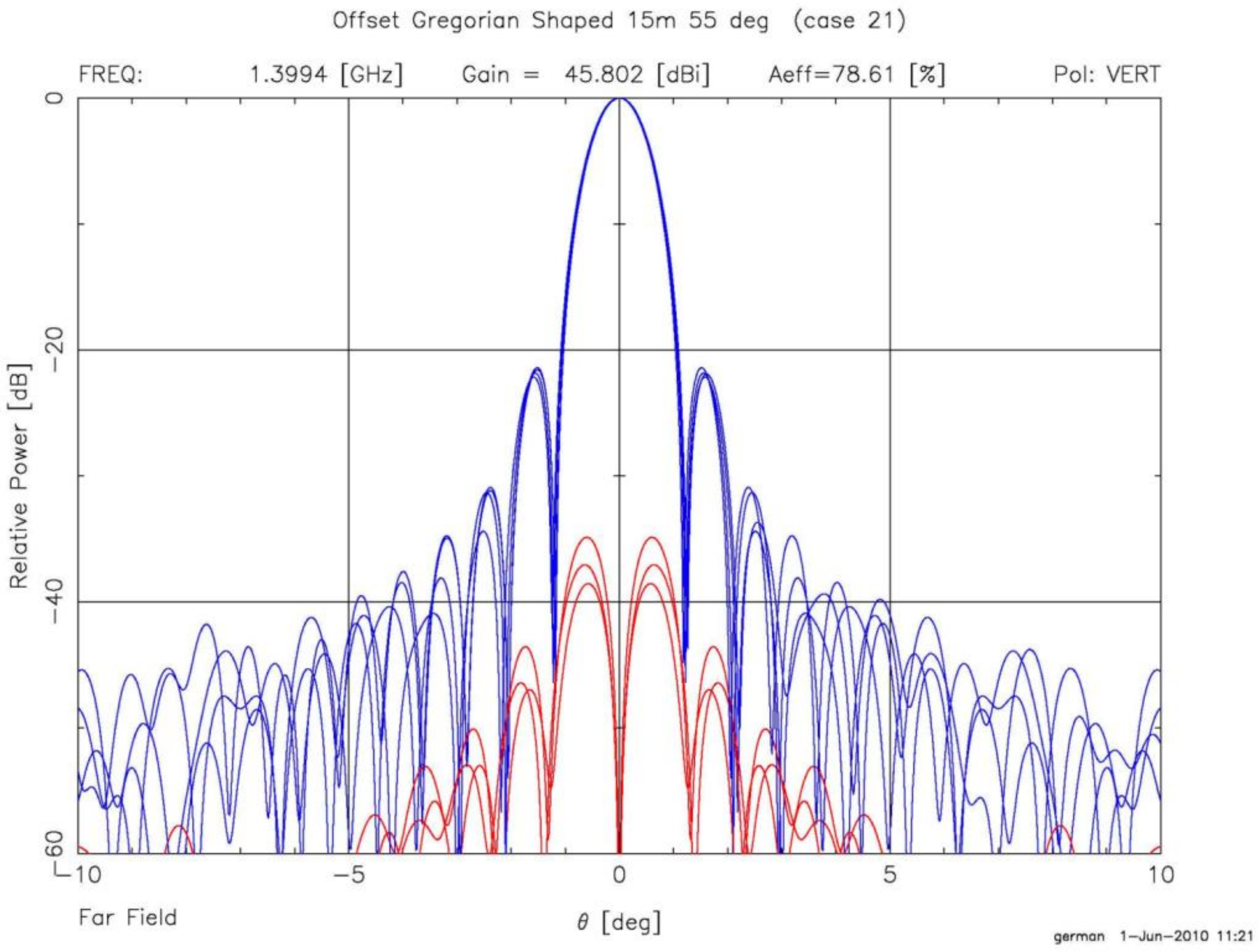


- Clear optical path, no blockage or scattering.
- Shaped optics, leads to very low spillover. (~ -50db wide angle)
- Very low spillover yields very low antenna noise temp. (<6 K ground)
- Very low spillover results in high rejection of RFI and strong sources.
- Shaped optics yield high efficiencies, total result is a high Aeff / Tsys.
- Ample space and access to mount multiple feeds on an indexer.
- PAF works effectively at either secondary or primary focal area
- Feed arm high chosen for structural cost reasons.
- Feed arm low may produce slightly lower spillover for some WBSPFs.
- Feed maintenance access via a standard bucket truck.
- Primary area is 22% over symmetric but antenna cost is 13% more.
- Primary surface accuracy will need to be <1mm rms, 1/30 λ.

More features will be listed in the structural design section.

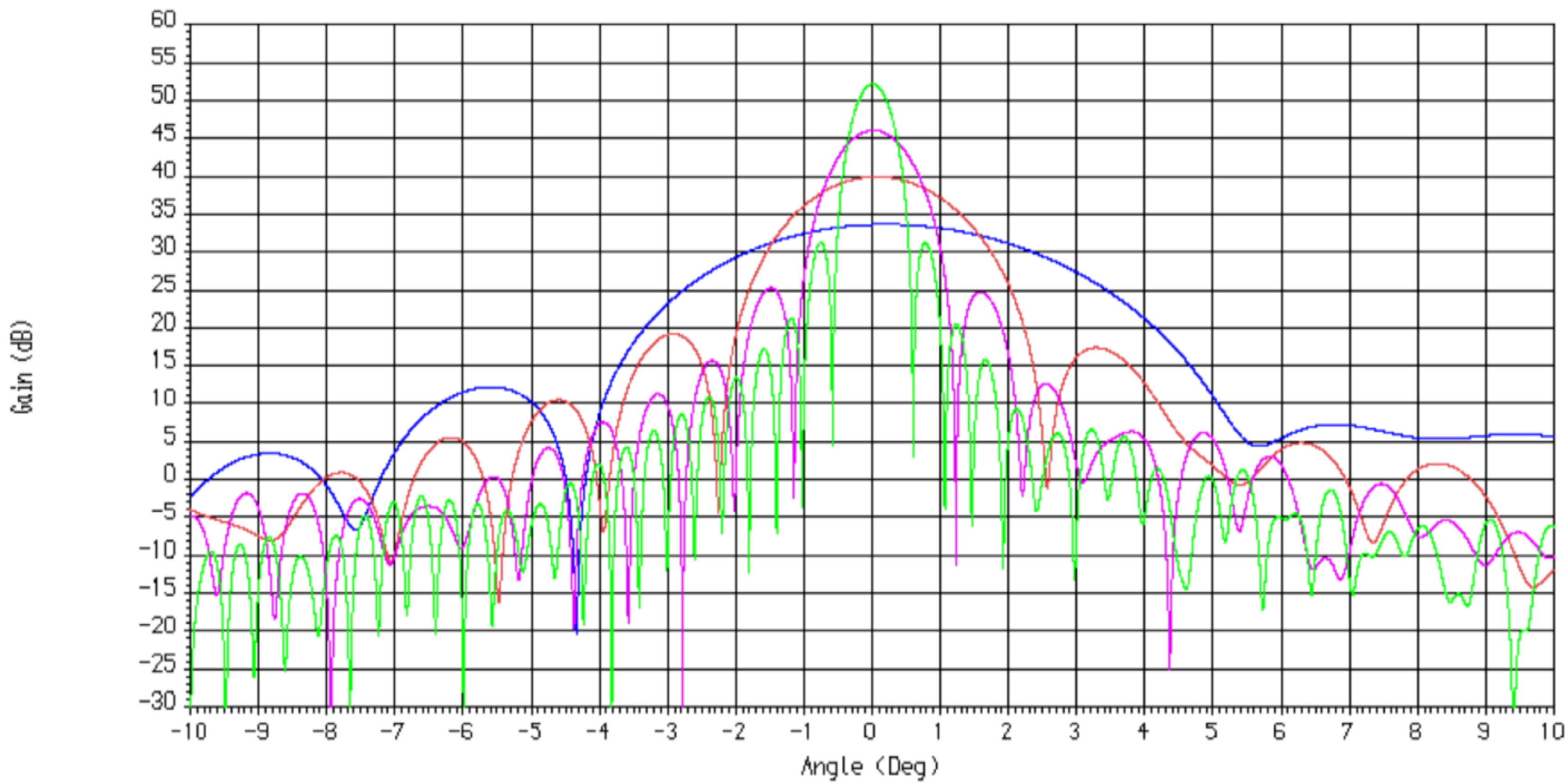
Optics Design

Beam Pattern, 1.4 GHz, Assumed Perfect Feed



Optics Design

DVA-1 Performance 0.35 to 2.8 GHz



Baker 2012-06-29 CDR

Optics Design

Low System Noise, Now & Future

Lowering Tsys is the most cost effective way to increase sensitivity

Present LNA’s need cryogenics to minimize noise contribution, expensive.

Ongoing trend is ever lower noise & future cryogenics should be lower cost.

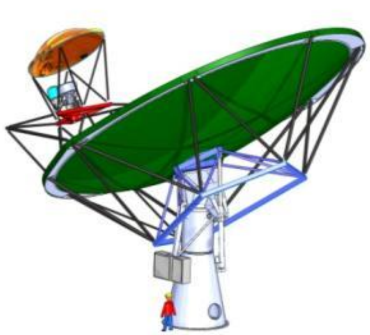
Reduce antenna noise contribution to absolute minimum now.

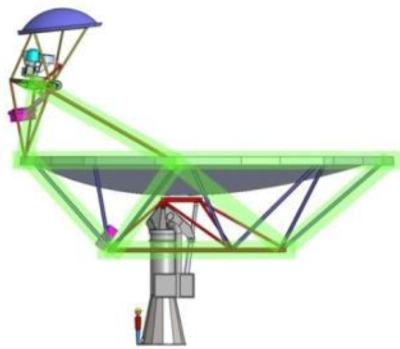
Deep edge tapers improve antenna noise but usually lower efficiency.

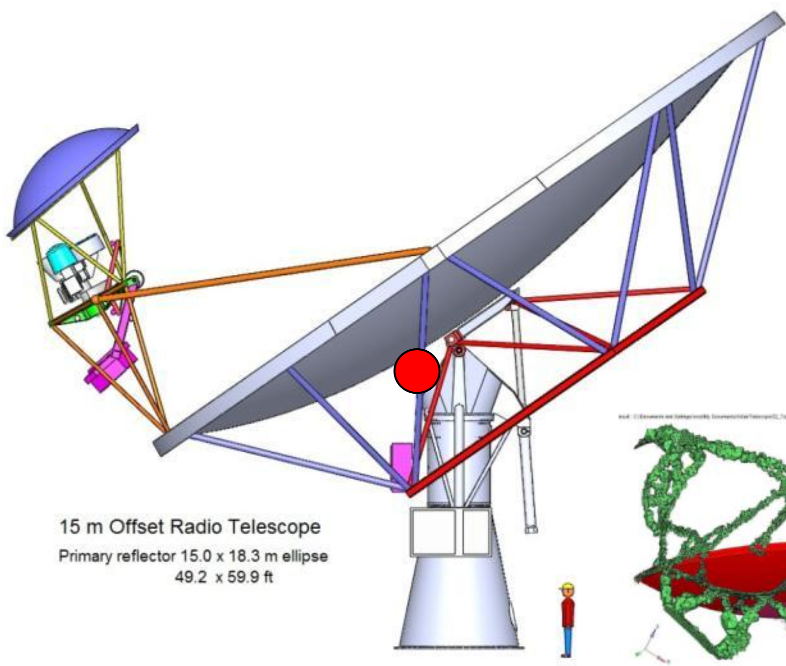
Shaping restores the efficiency and optimizes Aeff / Tsys.

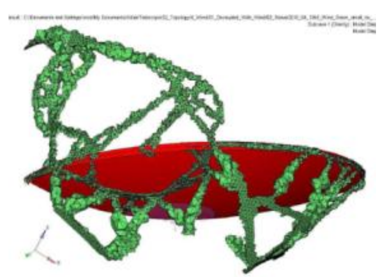
Structural Design

Antenna Features to Appreciate



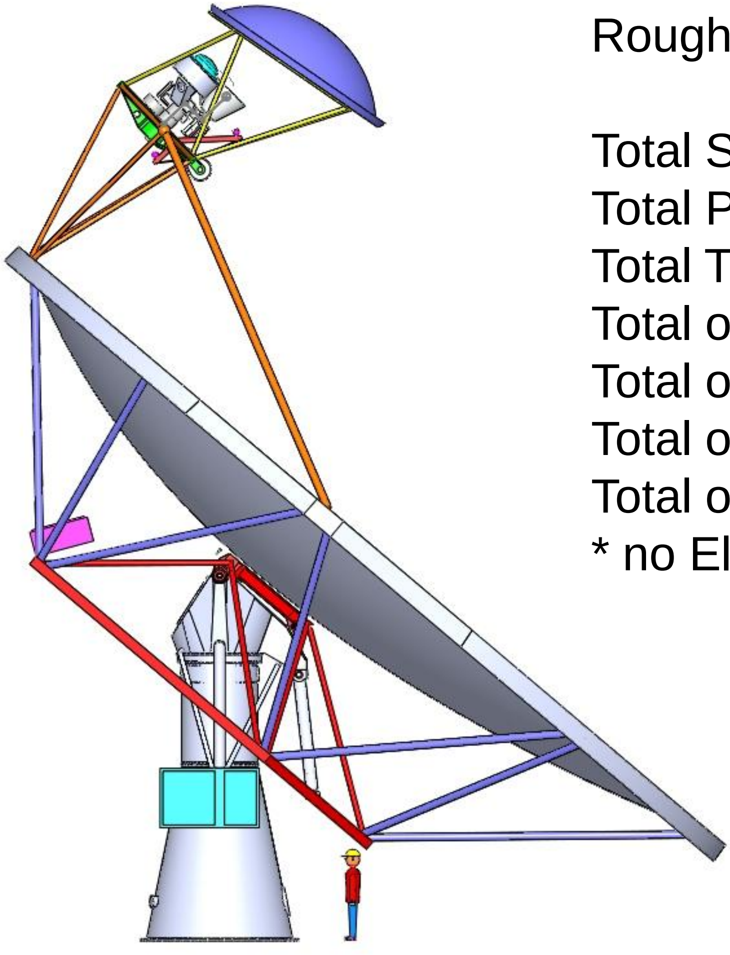






Reflector surfaces are structural members.
Rim supported surfaces are stable.
Unmatched CTE can be accommodated.
Offset low allows short Mount.
Circular closed deep truss support.
Primary support steel is majority CW.
Reflector set CM location is good.
Reflector Set & Mount interface is simple.
El backlash control via gravity.
Az backlash control via dual drive.
Stow position has low drive loads.
Mount exterior surfaces are load bearing.
Mount interior open for mechanicals.
Total antenna weight 47,000 lbs

Structural Design
Antenna Component Masses

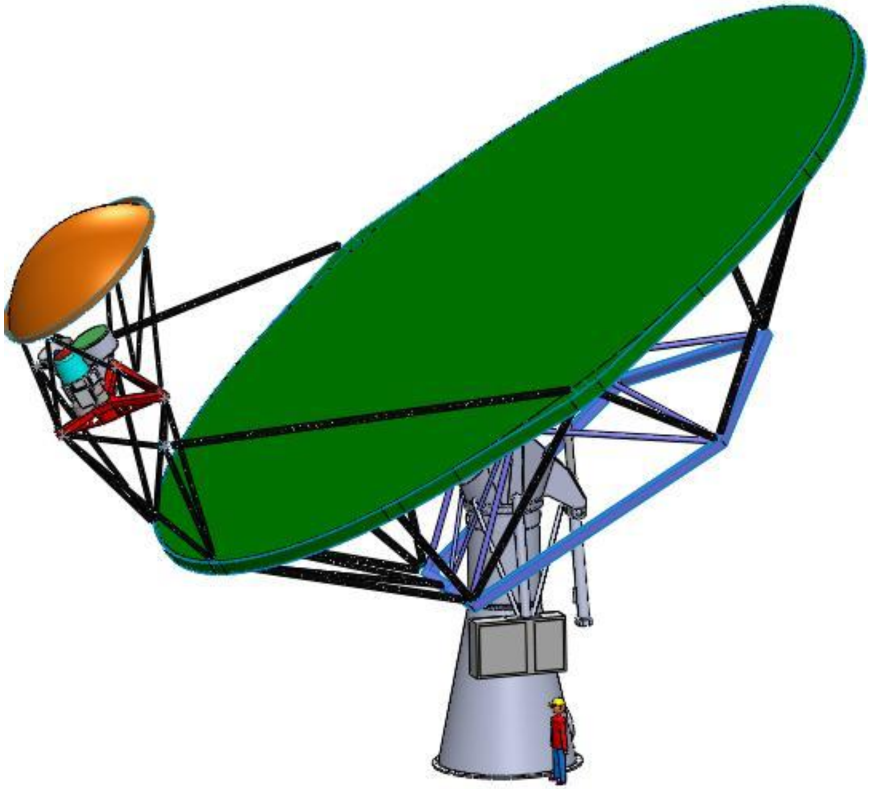


Rough Estimates on Weight

	kg	lbs
Total Secondary Assy	1,711	3,772
Total Primary Assy no CW	7,538	16,618
Total Turnhead Assy *	5,202	11,468
Total on El Bearings with CW	11,955	26,355
Total on Az bearing	15,697	34,606
Total on Pedestal	17,946	39,563
Total on Foundation	21,434	47,252

* no El Actuator

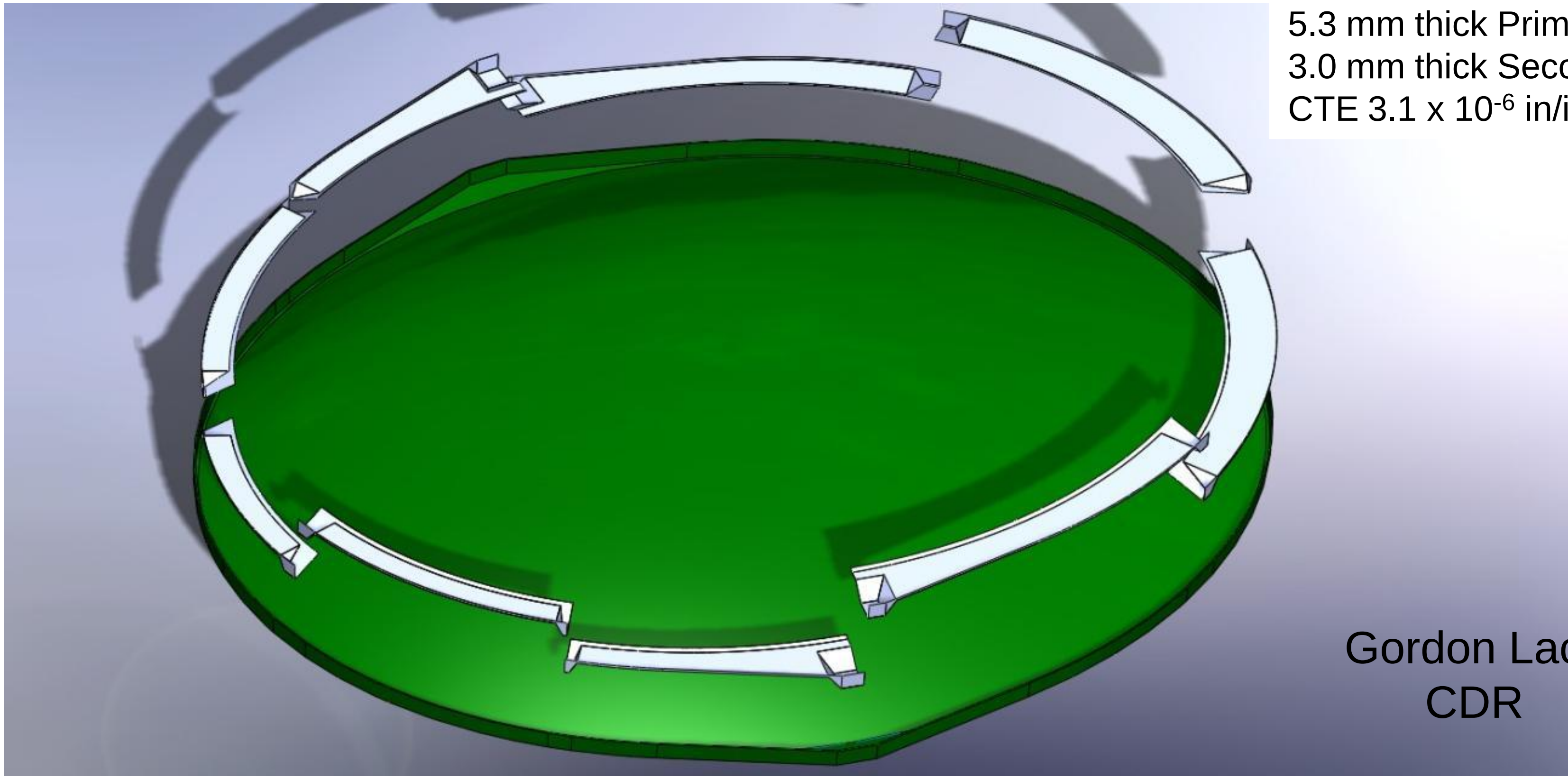
Principle Design Advantages of Molded Single Piece Composite Reflector:



- •High thermal stability, very low CTE
- •High part-to-part repeatability
- •No assembly labour
- •Very durable, zero corrosion
- •Very high strength
- •No panel gaps = higher efficiency, lower noise temperature

Shell & Rim Pieces

5.3 mm thick Primary
3.0 mm thick Secondary
CTE 3.1 x 10^{-6} in/in/F

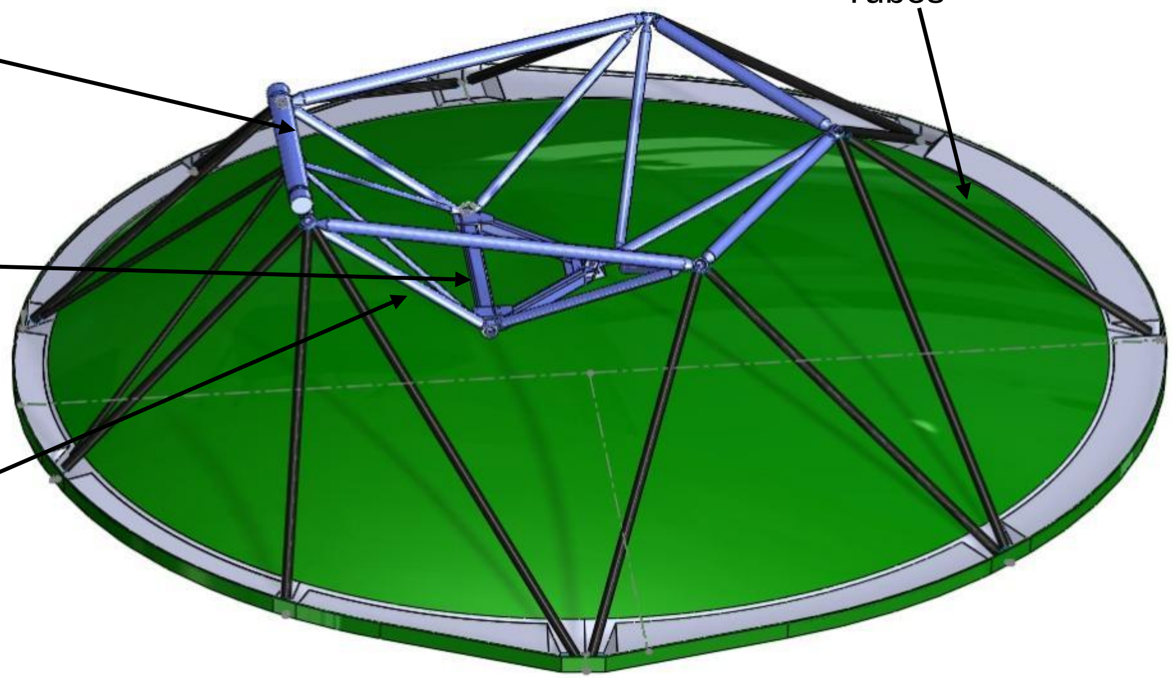


Function of composite backing pieces: to stiffen the rim of the dish and to spread the load from the outer backing support structure.

Backside Center Frame

Pentagonal Frame. Built up from round tubes and end fittings. A weldment here is not feasible because of the large size which precludes pre-assembly

Lighter Walled Outer Tubes

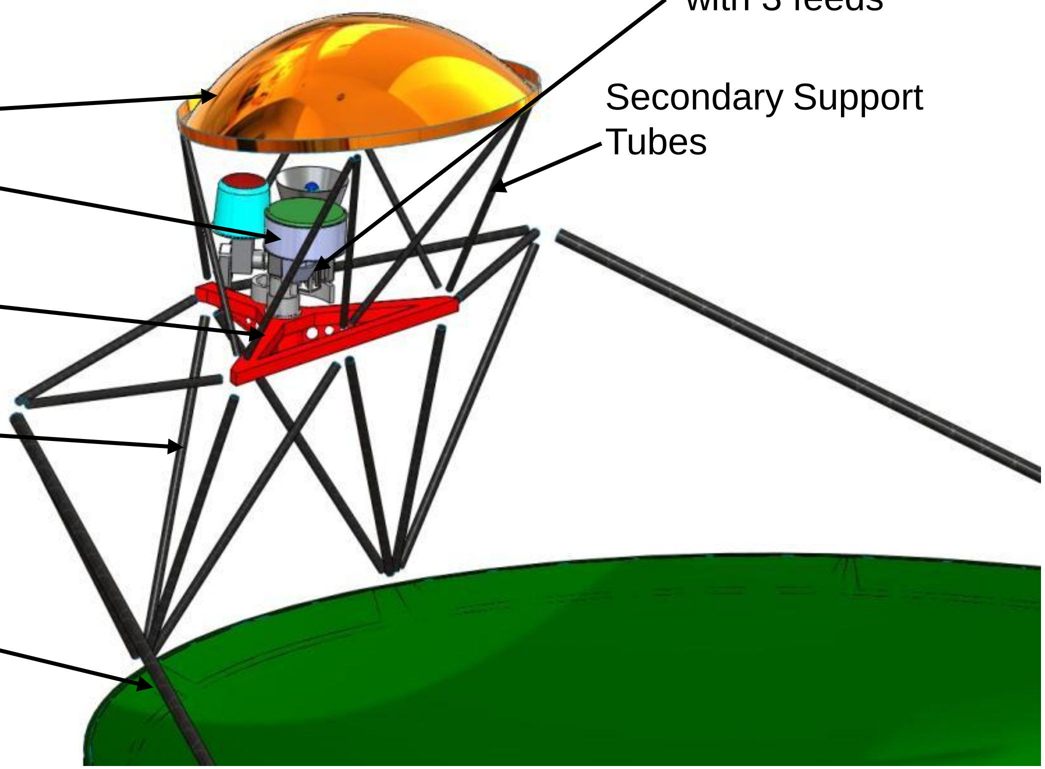


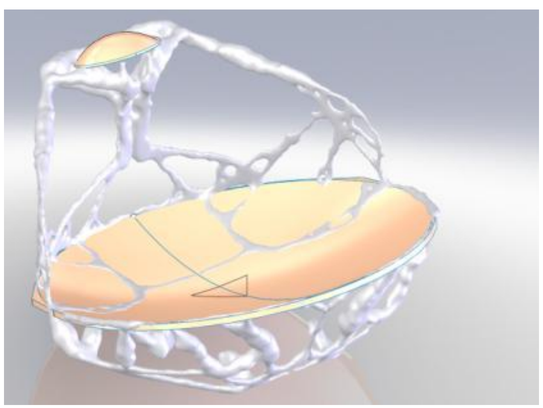
Triangular Square-Tube Weldment. Small enough to ship so it is welded

Heavy-Walled Steel Inner Tubes for Maximum Stiffness

- The tubular backing structure provides a very stiff foundation for the reflector surface
- Differential thermal expansion issues between dish surface and backing structure are also minimized

Feed Platform & Secondary Support



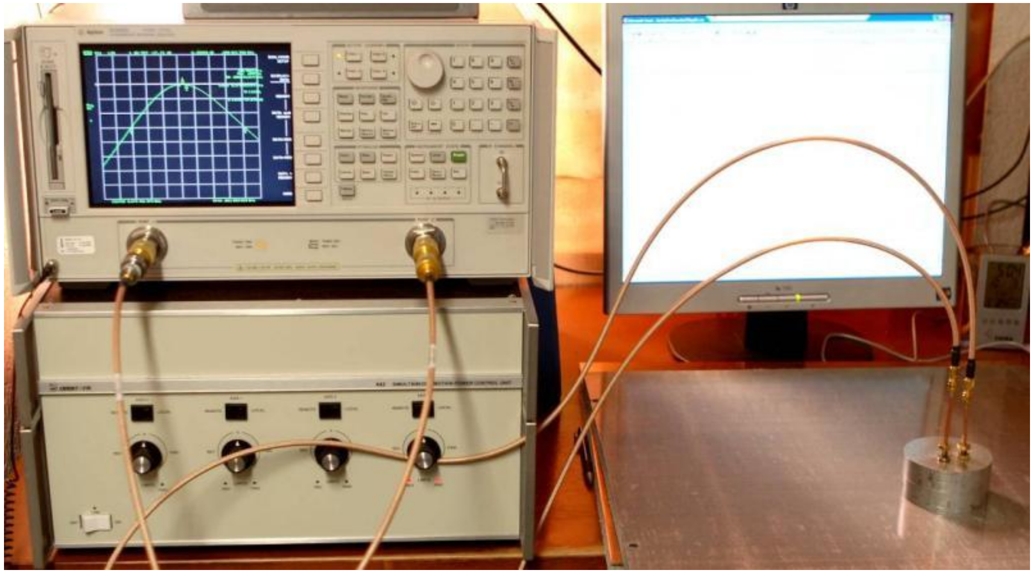


•The feedleg and secondary support benefited greatly from topological optimization studies

•Topological studies forced a rethink of earlier concepts and led ultimately to the simple and stiff design shown above

Reflector Design
Reflectivity Testing

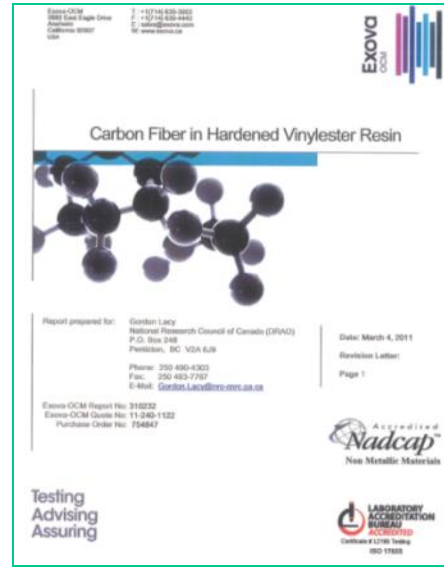
- Embedded reflective layer technology developed
- A circular cavity test method settled on after initial work with free space testing
- Testing currently includes 3 frequencies, 8.4GHz, 14.4GHz and 18.2GHz
- 100's of different combinations of materials tested since 2006
- Development continues at higher frequencies



Reflector Design

Materials Testing

- Materials testing ongoing since 2006
  - Resin/fibre Strength, stiffness, Poisson
  - Coefficient of Thermal Expansion (CTE) of resins and composite panels
  - Resin shrinkage, resin softening point (Tg, HDT)
  - In-house testing
  - Testing used to help determine most suitable composite materials


Exova OCM
Exova
Carbon Fiber in Hardened Vinylester Resin
Report prepared for: Gordon Lacy
National Research Council of Canada (DRAO)
P.O. Box 248
Penticton, BC V2A 6J9
Phone: 250 490-4303
Fax: 250 493-7767
E-Mail: Gordon.Lacy@nrc-cnrc.gc.ca
Date: March 4, 2011
Revision Letter:
Page 1
Exova-OCM Report No: 310232
Exova-OCM Quote No: 11-240-1122
Purchase Order No: 754847
Accredited Nadcap Non Metallic Materials
Testing
Advising
Assuring
LABORATORY ACCREDITATION BUREAU ACCREDITED

Composites Innovation Centre	Test Type: Shrinkage from Cure	Test #: 1/3
	Test Date: 8 February 2010	Project Number: 09-095-04
Material: Hetron 922	Test Personnel: Lisa Hibbert	W.A. #: N/A

SHRINKAGE FROM CURE

APPLICABLE CONTRACTS, DRAWINGS, SPECIFICATIONS, STANDARDS

Company	Document
ASTM	D792-00 Standard Test methods for density and Specific Gravity (Relative Density) of Plastics by Displacement

Industries Involved	Liaison	Contact Information
NRC	Gordon Lacy	250-497-2340

SAMPLE INFORMATION

Source	Ashland via NRC
Material(s)	Hetron 922 vinyl ester infusion resin, Norox CHP cumyl hydroperoxide initiator
Description	Medium brown resin, cured to transparent solid

TORAYCA

Results

Toray Carbon Fibers America Technical Center		ge Longitudinal ((µin/(in·°F))		Transverse CTE ((µin/(in·°F))
3TEX Laminate	2.03	2.21	**2.12**	**2.96**
QISO™ Laminate	3.16	3.01	**3.08**	**3.17**

Reflector Design
Material Choices

The performance of a composite structure is highly dependent on the choice of constituent materials, the fabrication methodology, and the structural design.

- **Resin choice: Vinylester**

  Reason: low cost, sufficient strength, good chemical stability, and well suited to Vacuum Infusion Process.

- **Fibre choice: Carbon fibre**

  Reason: highest thermal stability, highest thermal conductivity, highest stiffness.

- **Fabric choice: Triaxial Braid**

  Reason: highest dimensional stability available, highly orthotropic, very high damage tolerance

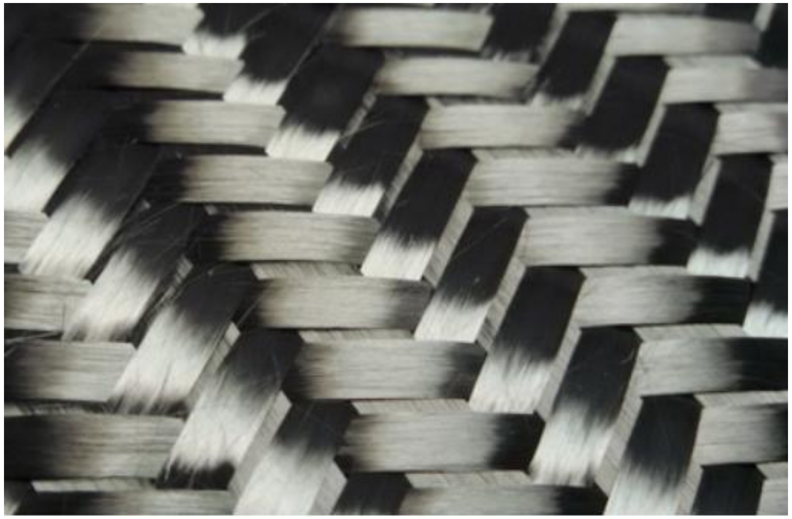

Technical Datasheet
Ashland Performance Materials
HETRON®

HETRON® 922 Corrrosion/Heat Resistant Epoxy Vinyl Ester Resin

HETRON 922 resin is a low viscosity, unpromoted patented epoxy vinyl ester resin with F-Cat technology. This patented technology results in a resin that exhibits no foaming, excellent exotherm control, and industry-leading storage stability.

The raw materials used in the manufacture of this resin are listed as acceptable in FDA regulation Title 21 CFR 177.2420 for repeated use in contact with food, subject to user's compliance with the prescribed limitations of that regulation. HETRON 922 epoxy vinyl ester resin gives final products with:

- Excellent corrosion resistance
- Excellent impact strength
- High tensile elongation



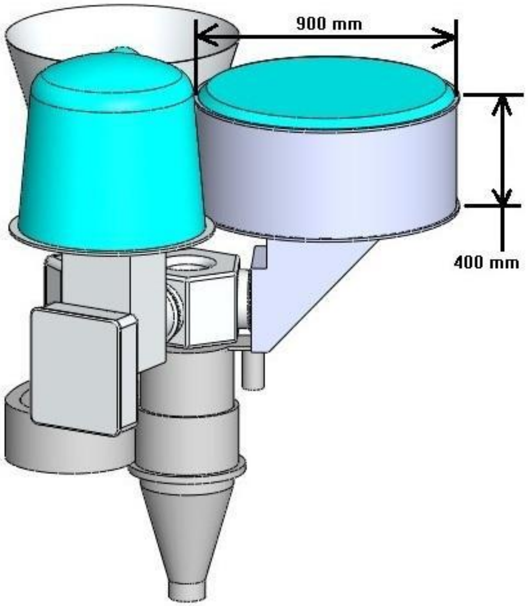
Reflector Design

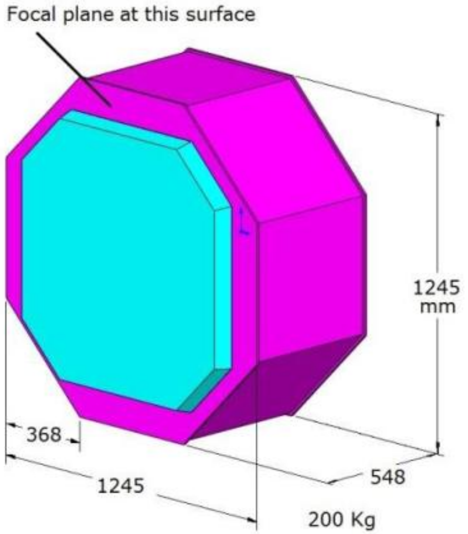
Materials Development, Other

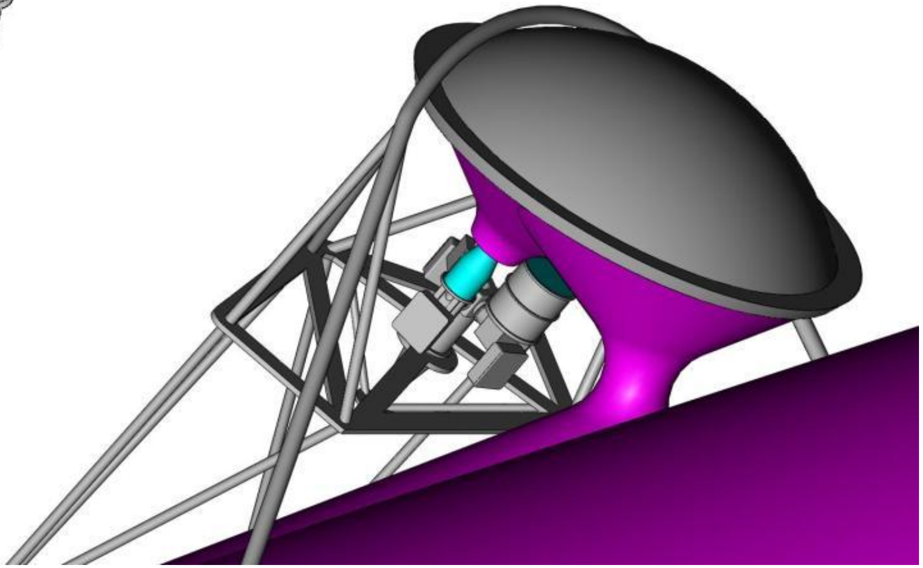
Additional Material Requirements:

- Creep: A design consideration, alleviate through proper design.
- Fatigue: A design consideration, but not much of a concern in our low stress, low cyclic loading environment
- UV stability: Block UV with good long life paint
- Water absorption: Low humidity desert environment equals low absorption, design for slight strength loss.
- Hail damage: Composite panel is more resistant to hail than comparable aluminum panel.

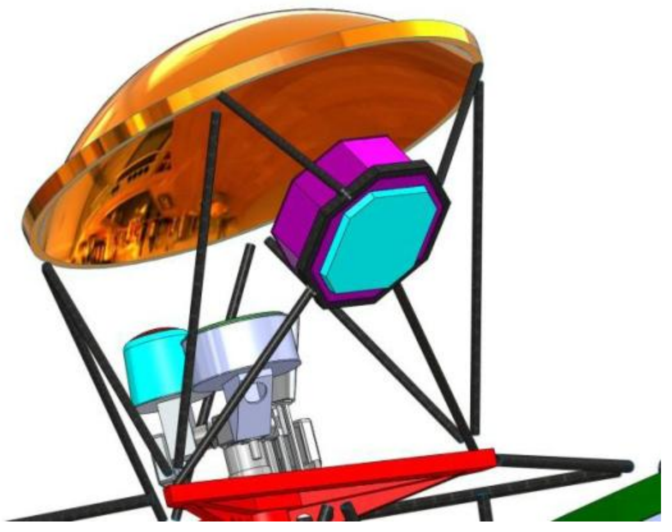
Feeds and Feed Indexer Concepts

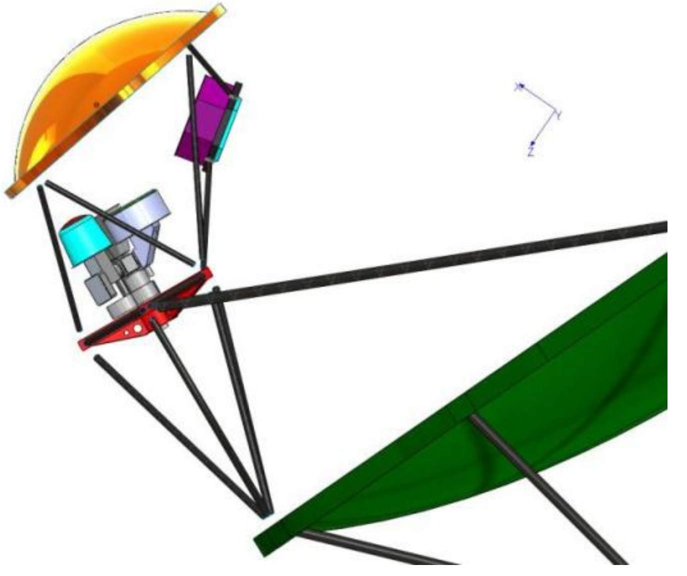






Secondary & Feed Platform



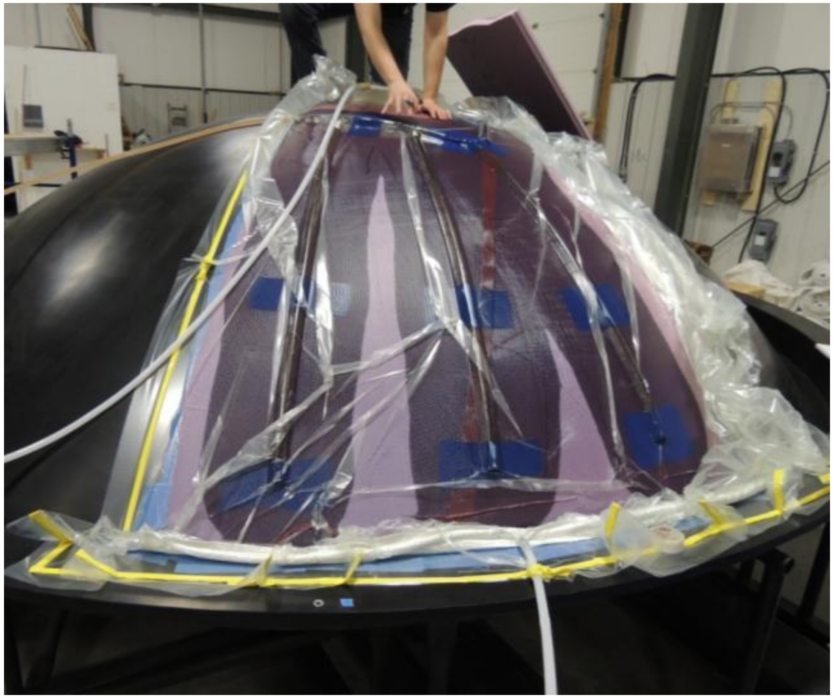


Secondary reflector	150 Kg	FRP composite
Secondary support	40 Kg	FRP tubes 75mm dia. Various thicknesses
PAF & positioner	350 Kg	Steel
SPFs & indexer	380 Kg	Steel & alum
Feed platform	200 Kg	Steel
Platform support spars	170 Kg	FRP tubes
Total forward of primary:	1290 Kg	Not optimized

Reflector Fabrication

Vacuum Infusion Process (VIP) chosen because:

- fabrication of very large structure possible
- autoclave, fibre placement machine (necessary for ‘prepreg process’) not required
- part quality and properties very close to prepreg



15m Mold Inside Building

Finished part:
15.0 m (49.2 ft) wide
18.3 m (60.0 ft) long
5.3 mm (0.209 in) thick
2730 kg (6019 lbs) painted

4m Secondary Mold & Materials

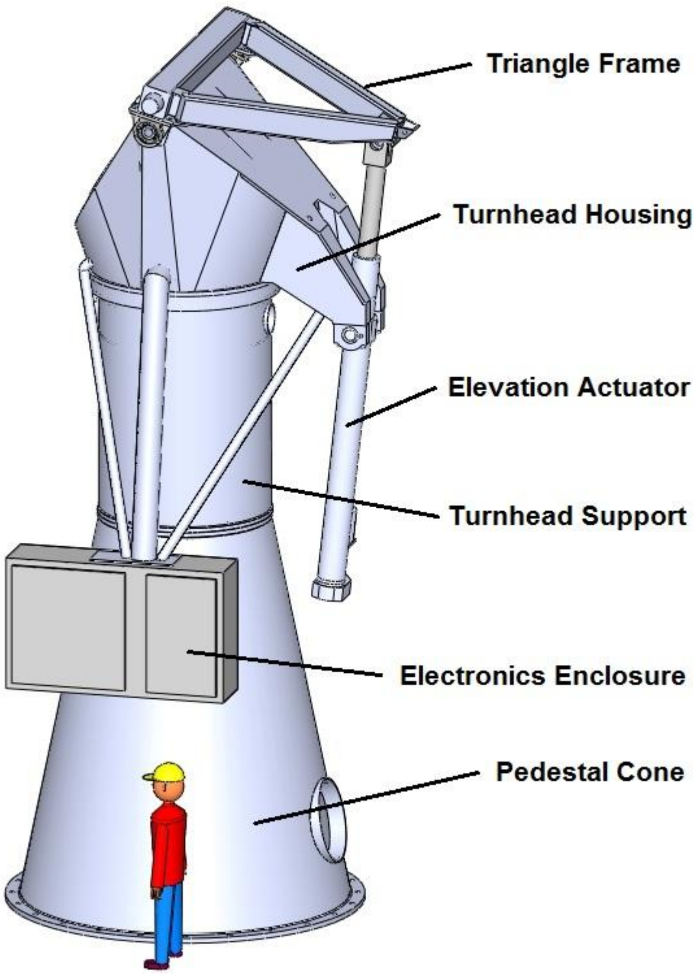
Finished part:
4.0 m (13.1 ft) wide
3.0 mm (0.118 in) thick
108 kg (238 lbs) painted

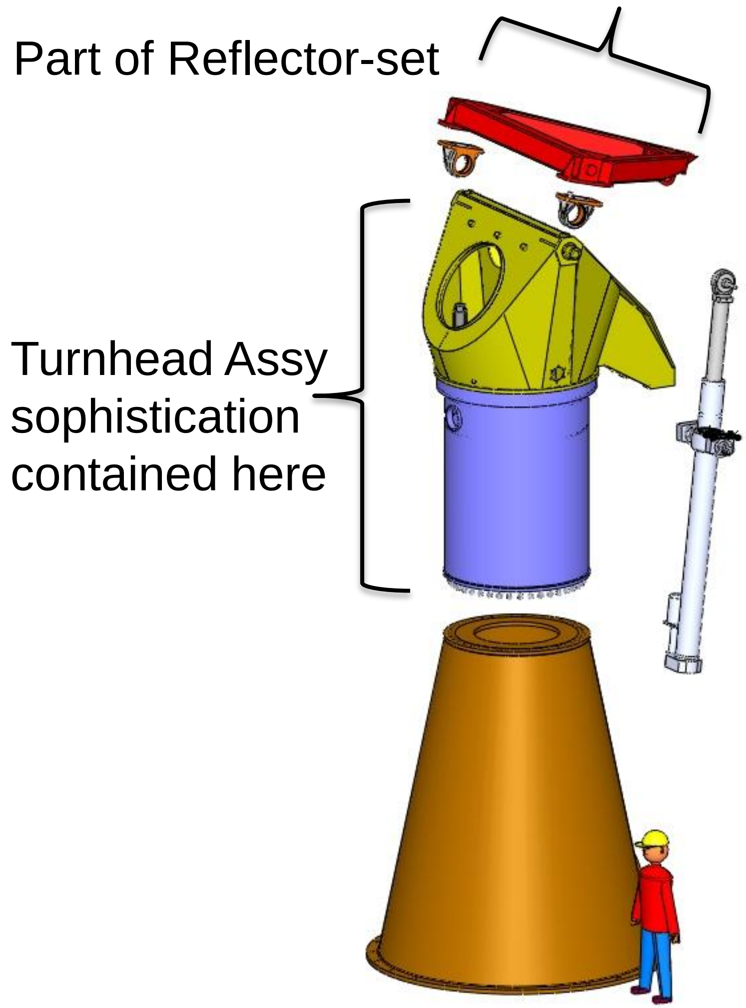
Tower and Turning Head

Key Features:

- Feed up design allows short, stiff, and less expensive steel tower
- 60 month maintenance interval.
- Tilt meters installed for improved pointing performance
- Internal azimuth gear with oil bath allows remote detection of oil contamination
- Enclosed rod and cylinder type linear elevation drive also with oil lubrication

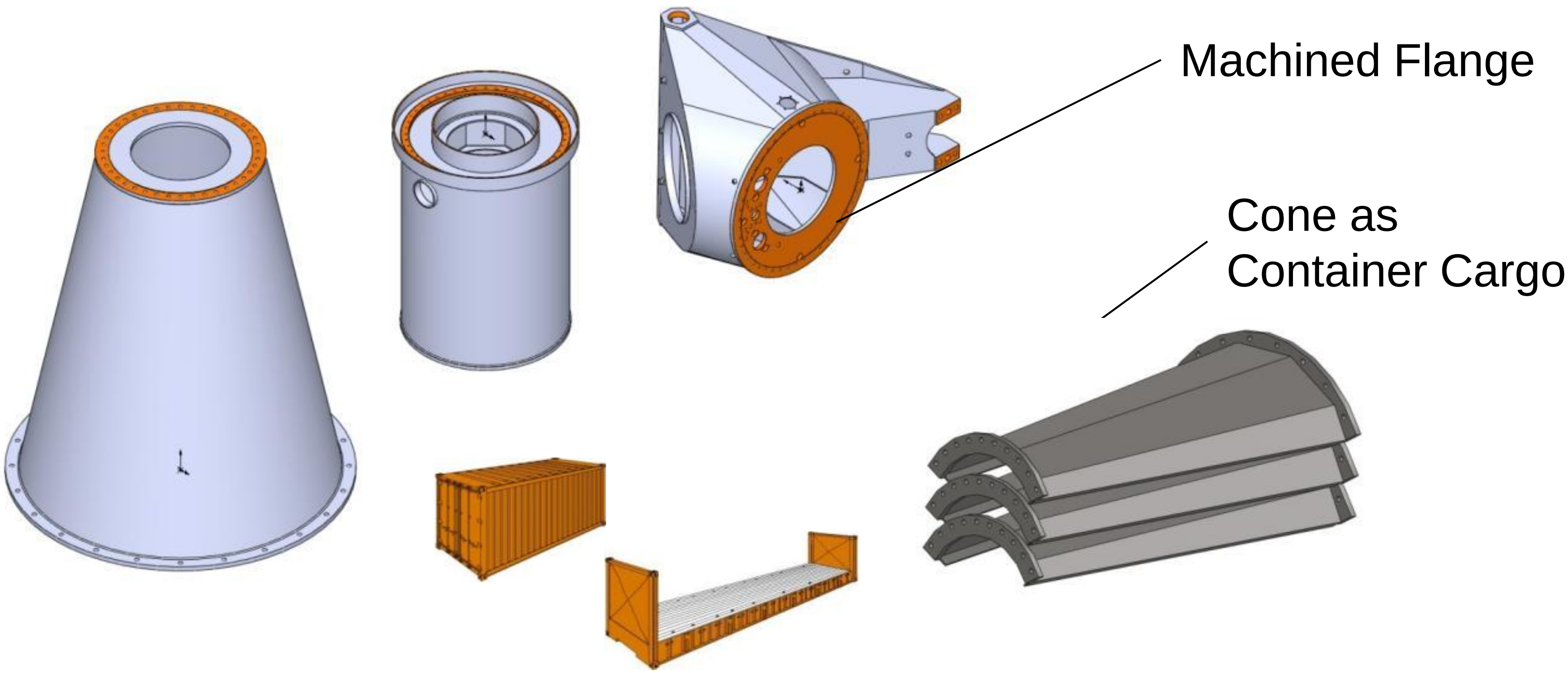
Major Mount Components and Deliverables



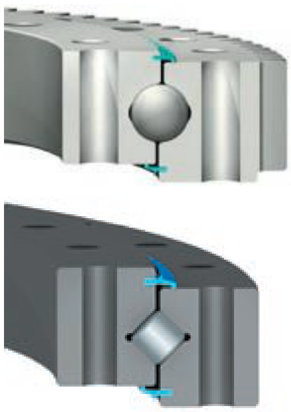


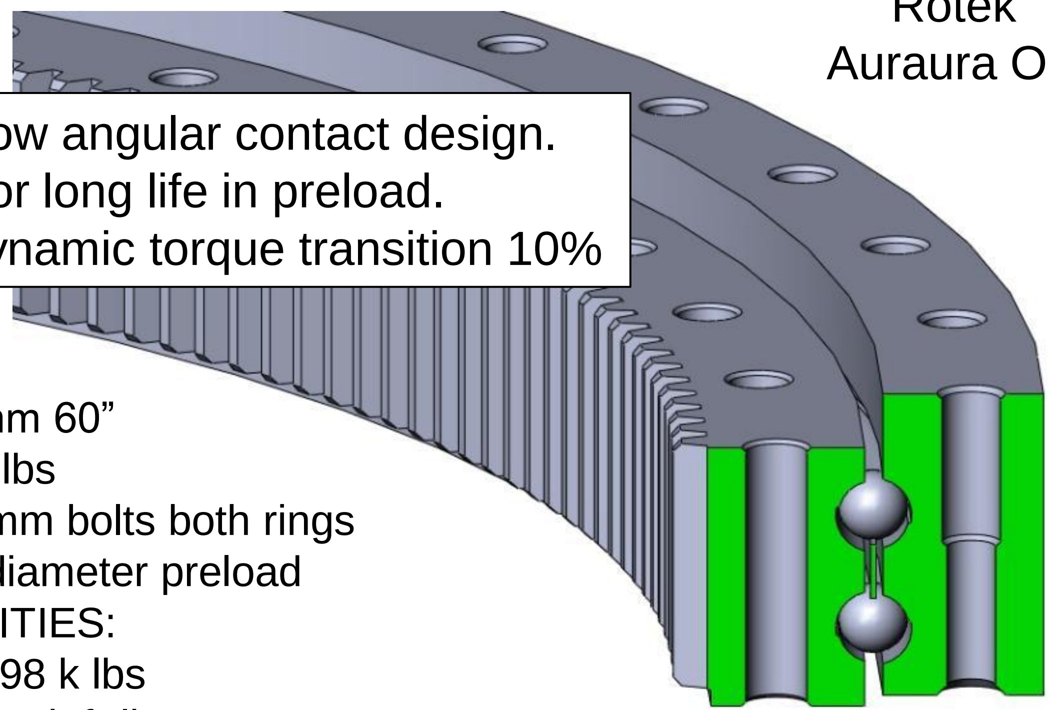
Large Structural Pieces

•Azimuth Bearings require a very flat mounting surfaces.
•Support section has important features, drum top, tube length greater than diameter. Errors at lower flange transfers 13% through to upper flange.
•Turnhead attempts to move loads to outer skin and onto bearing.



Mount Design
Azimuth Bearing





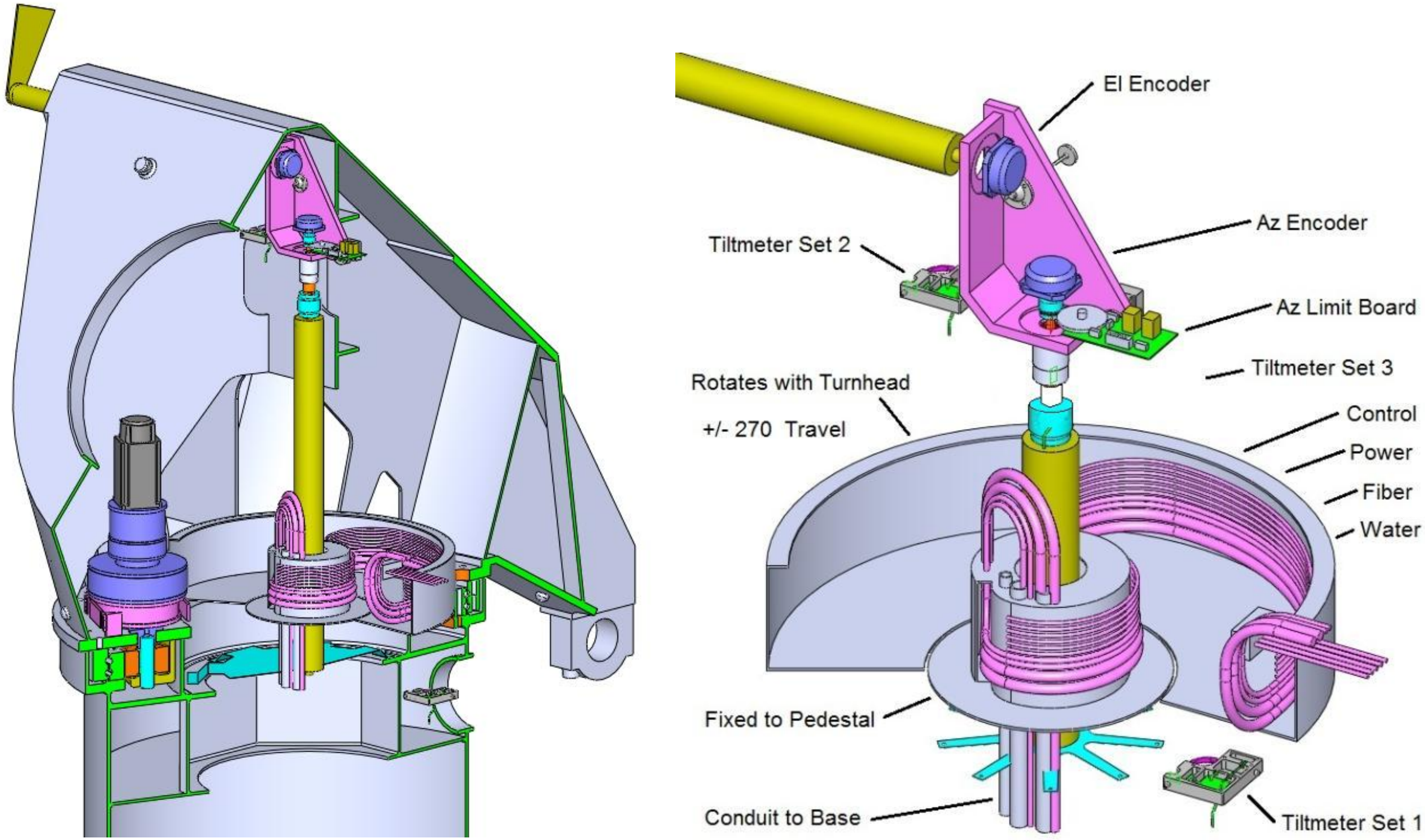
Rotek
Auraura OH

Double row angular contact design.
chosen for long life in preload.
static / dynamic torque transition 10%

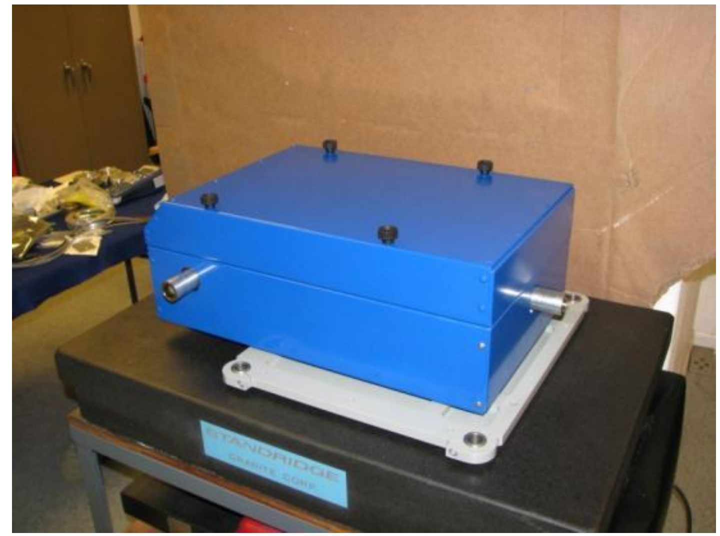
a) Ball path diameter 1524mm 60”
b) Dimensions 442 kg 975 lbs
c) Bolt pattern 48 holes 20 mm bolts both rings
d) Zero clearance to 0.002 diameter preload
e) Capacity STATIC CAPACITIES:
f) Axial: 3,105 kN 698 k lbs
g) Moment: 1,083 kNm 799 k ft-lbs
h) Radial: 707 kN 159 k lbs
i) Turning torque table top: 35 Nm, 26 lb-ft,
j) Turning torque installed: 84 Nm 62 lb-ft
k) Moment stiffness: Installed measurement underway.

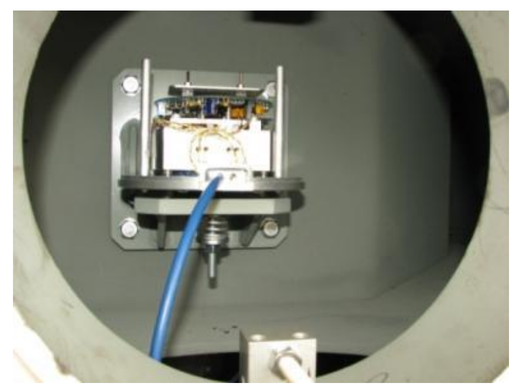
0.22481 lbs / N
8.8507 lb-in / Nm
145.04 psi / MPa

Metrology System



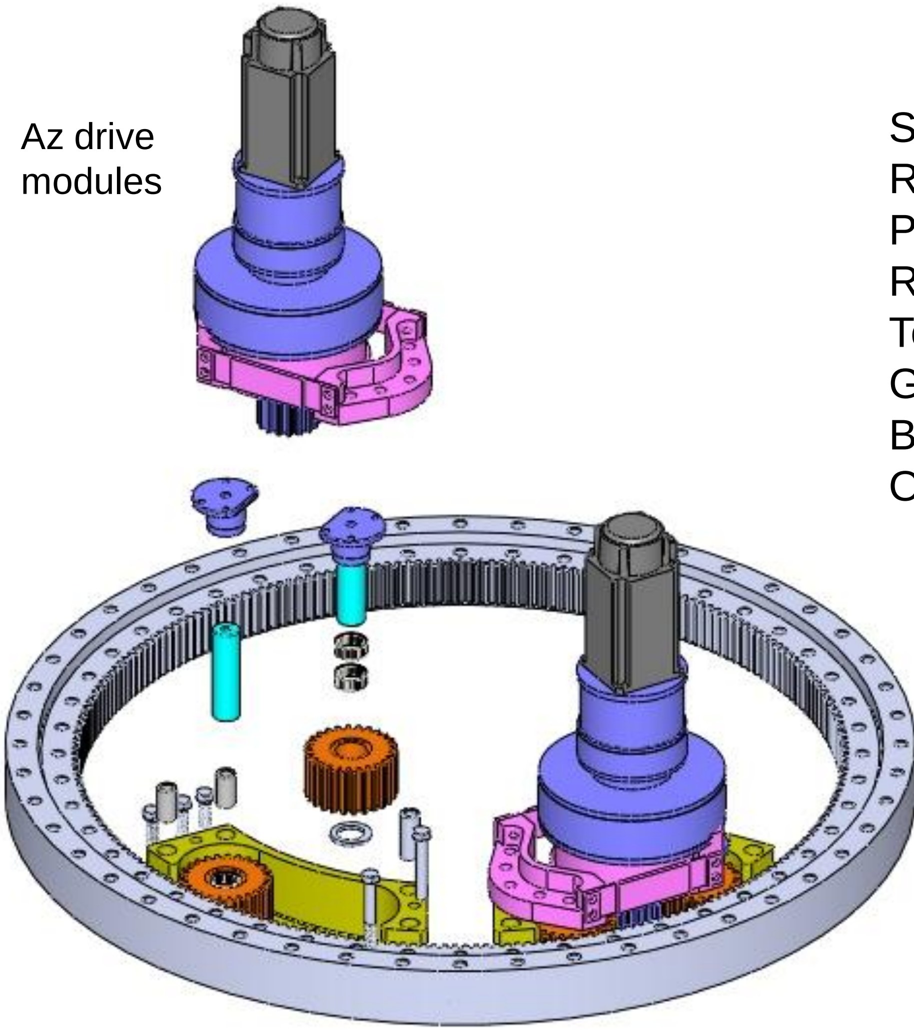
Metrology System





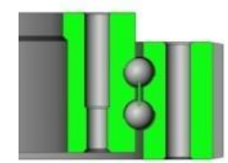
Az Drive Exploded View

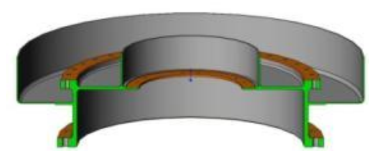
Az drive modules



Slew speed 3.0 deg/sec
Reducers 159 kg (350 lbs)
Pinion ratio 12.889
Reducer ratio 377
Total ratio 4860 az axis to motor
Gears are M6 module about 4.233 DP
Bull 232, Idlers 26, pinion 18 teeth.
Oil bath lubrication.

Bearings and gering in oil bath.





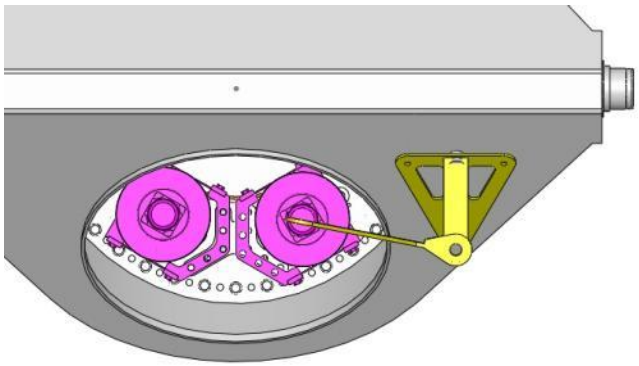
Az Bearing & Drive Parts

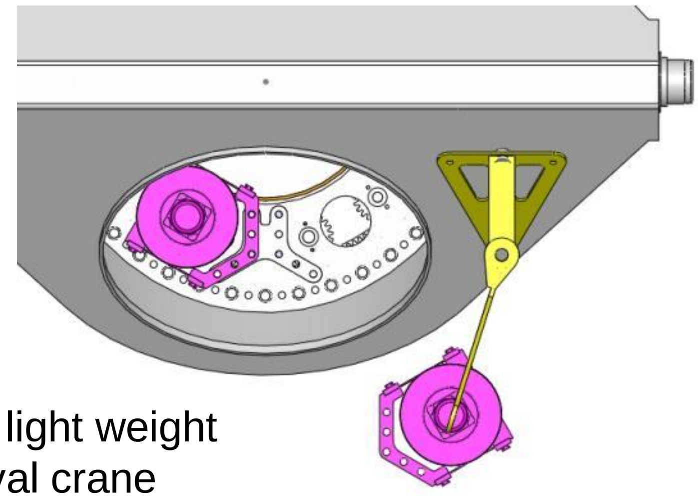
Unit weight 350 lbs

Oil bath lubricated

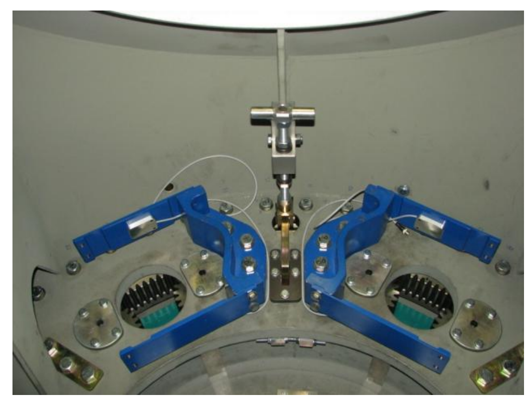
Pumped oil lubrication

Removal of Reducer Module

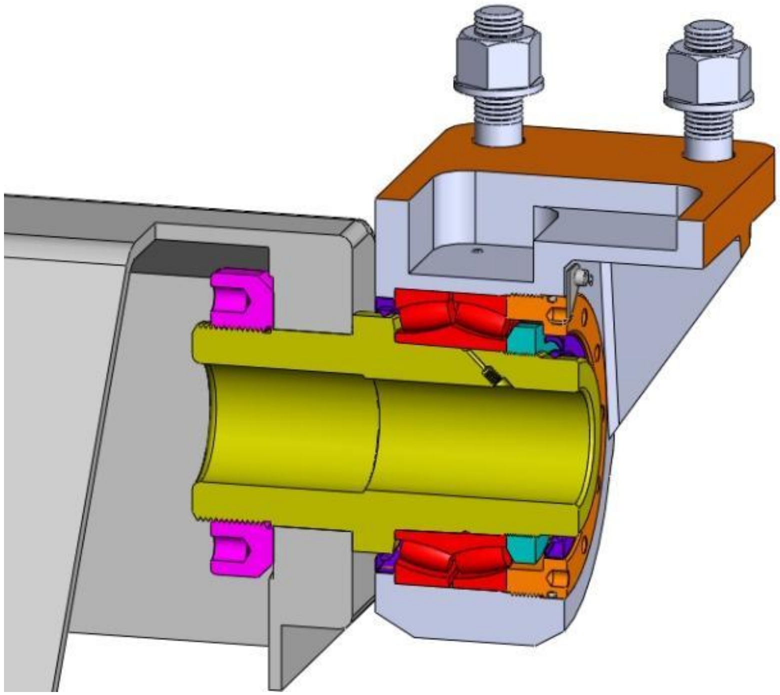




Small light weight
removal crane
snap on installation



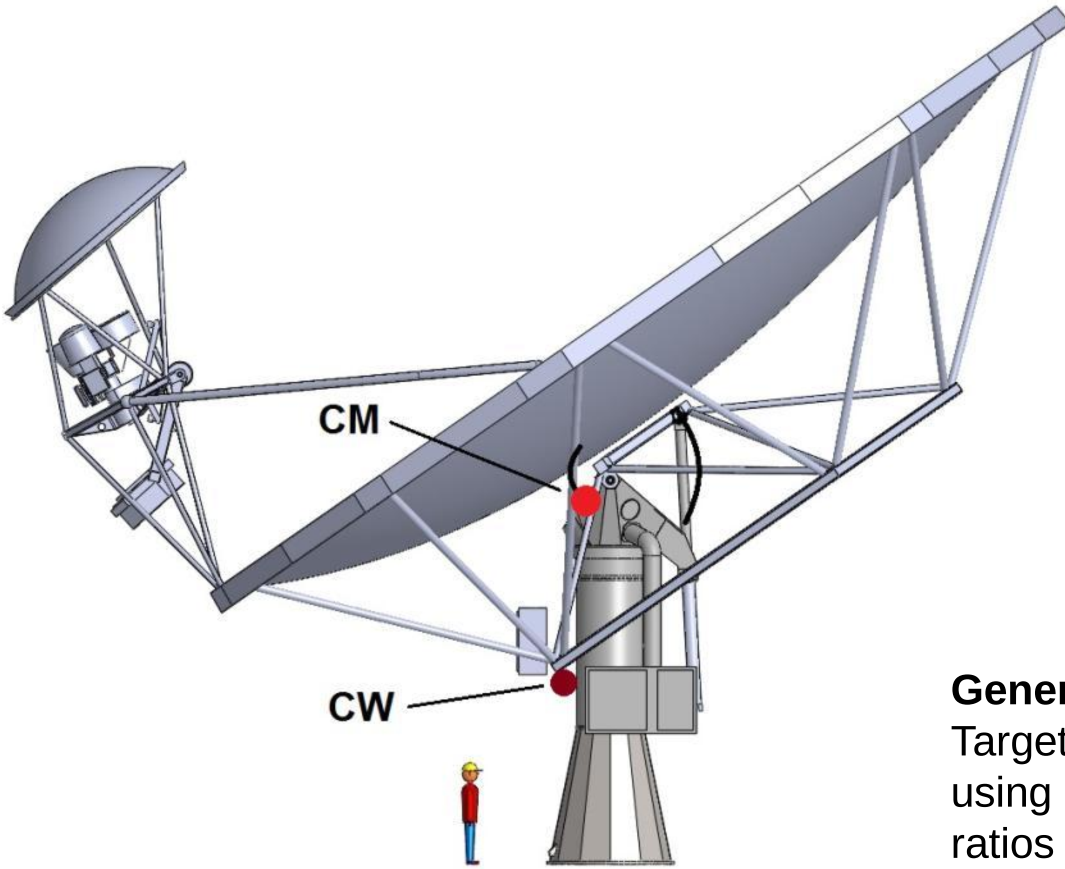
Elevation Bearing Design



Features
•Designed for minimum cantilever
•Bearing is fairly common and available.
•Allows for large hole to interior.
•Turnhead housing bored only.
•Bearing outside ring pressed in.
•Bearing inside ring taper expanded.
•Exposed shaft and cap parts are plated.
•Seals are high quality press in type.

Replacement
• Bearing and shaft are replaceable in position, with special tools.
• Housing removable via 4 bolts and hydraulic release on bearing bore.
• Shaft removable via remove internal nut and use hydraulic pulling tool,

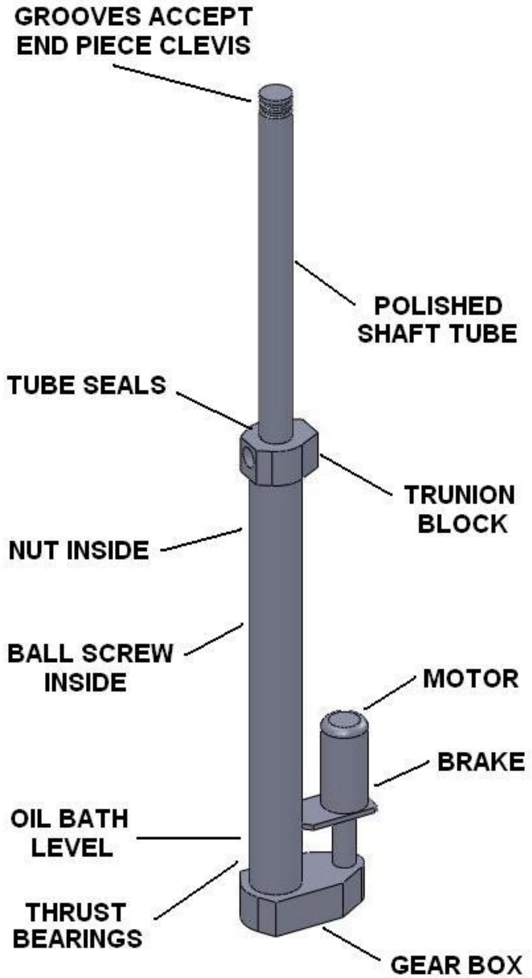
Elevation Drive Balance



The elevation axis has been positioned so the center of mass is at a reasonable radius of about 0.583 m.
The counter-weight CW has been tuned to locate the CM for best anti-backlash effect.
The actuator has about 48,000 N or 10,790 lbs.
2,122 kN nut.
1,736 kN col lim 3.62 SF

General notes:
Target slew is 0.75 to 1.00 deg/sec slew using a 2400 rpm motor gives ratios of 14,000:1 to 19,000:1

Actuator Key Components



Also needs: oil pump, oil level sensor, spring brake, effective seals.

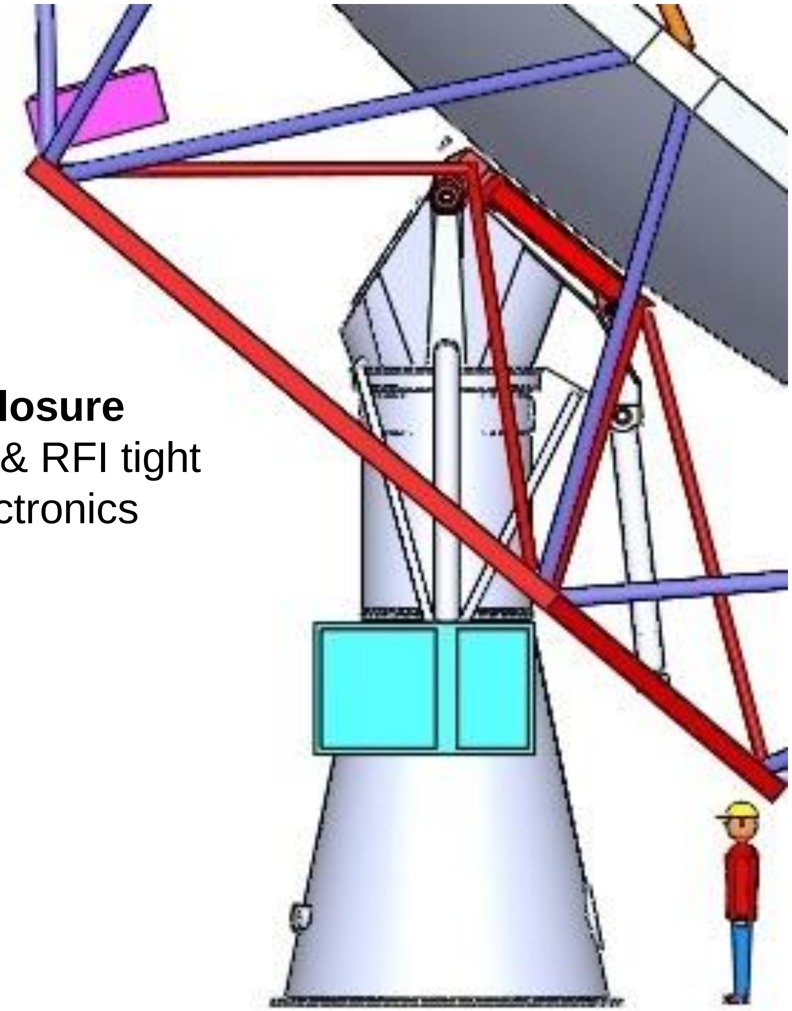
Limits may be part of the actuator or at internal elevation encoder

El Drive Fabrication

Electronics Enclosures & Access

Turnhead interior space
RFI tight
Encoders inside
Limits inside
Az wrap inside
Az reducers & motors inside
El drive motors near

Dish Enclosure
Insulated & RFI tight
Feed electronics



Turnhead Pendent enclosure.
Elevated for security
Insulated & RFI tight
Antenna control
Emergency stop
Power supplies
Servo Amplifiers
Air blower & filter
Water chiller

Finished Mount Parts

Fabricated in Los Angeles Area

Pedestal Cone on Mill

Turnhead Support on Lathe

Turnhead Housing on Mill

Conventional machines
and conventional tolerances
typical +/- 0.002” & +/- 0.003”

Turnhead Housing on Mill

Turnhead Proof Assy

at Minex Antioch

Mount Ready for Transport

Triangle Frame Dish Attachment

Installing Backup Structure

- Quick assembly, 6 hours, 5 to 6 workers
- Design allows lifespan (post-assembly) adjustment of primary reflector surface at rim

US SKA TDP NRC·CNRC

May 7 2014: Final Lift.

Ready for Testing

September 2014

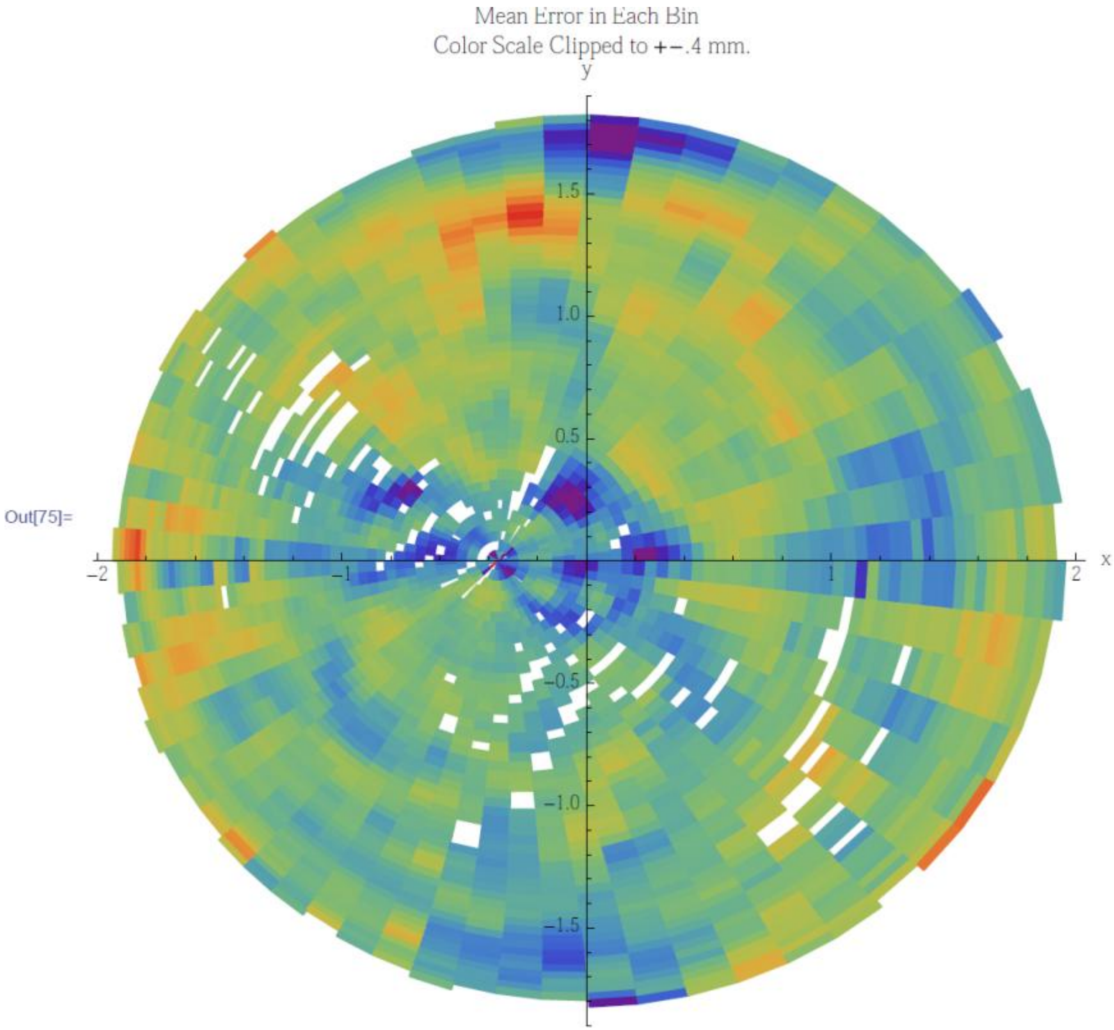
Secondary Reflector Scan

DVA-1 Secondary surface

0.20 mm RMS part
no aperture weighting

0.16 mm RMS part
with aperture weighting,

Much better results are possible as shown with subsequent similar parts.

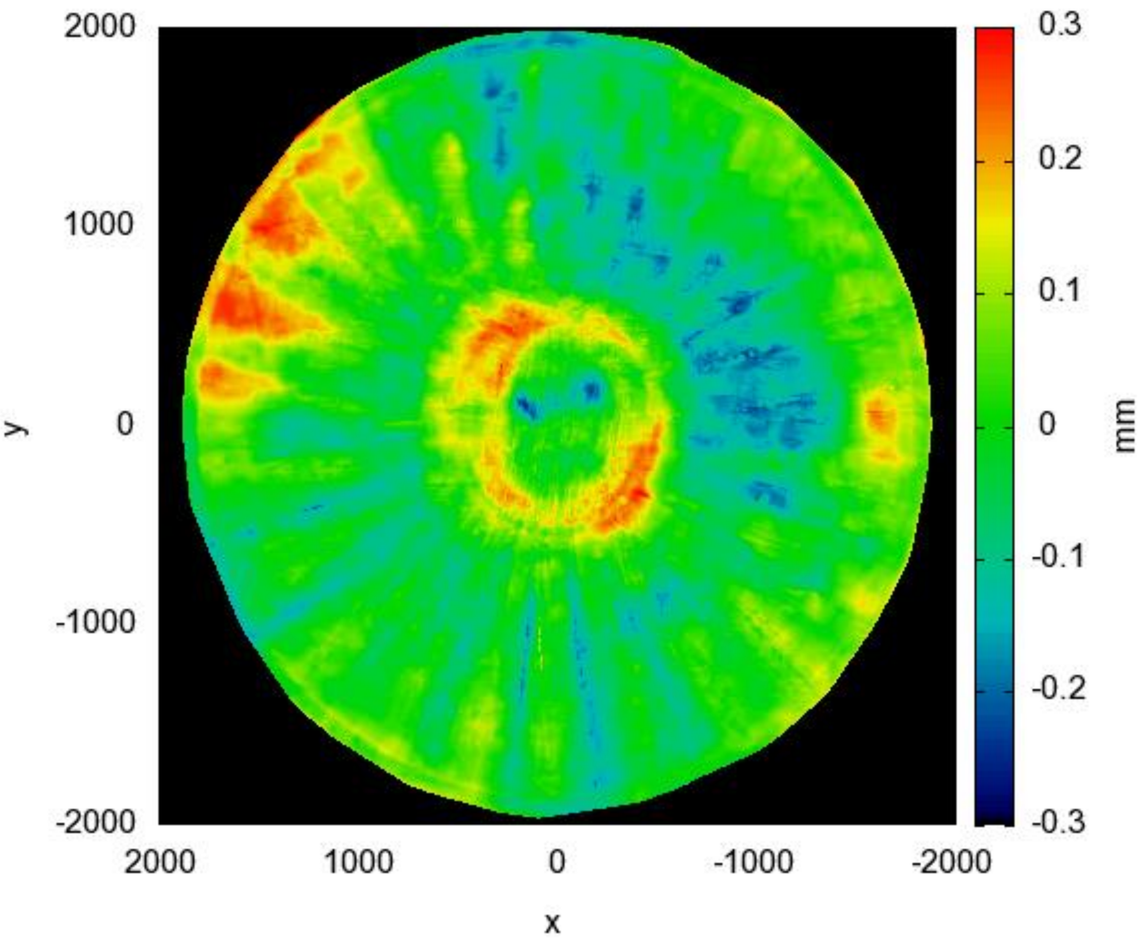


Improved Results Expected

Based on GDSatcom Secondary Reflector

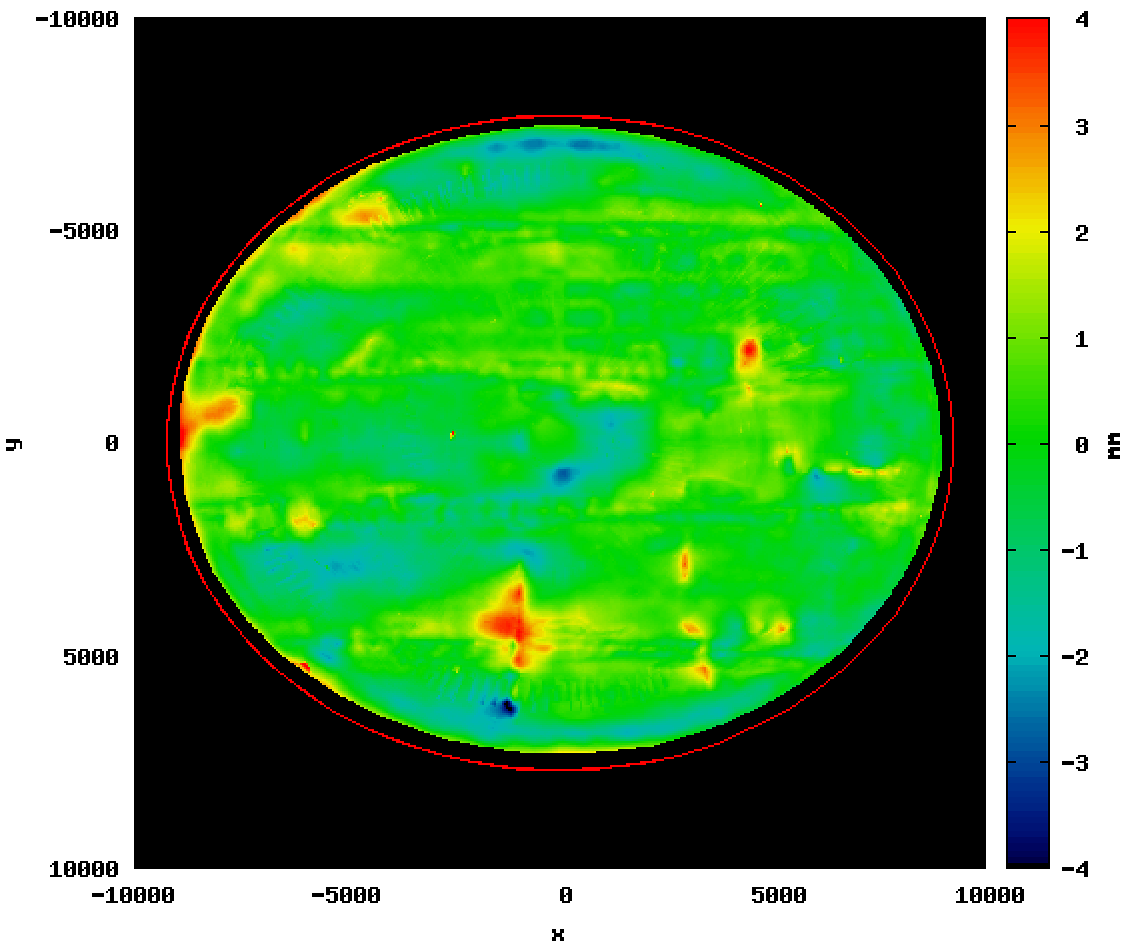
- NRC has now built two sub reflectors for the GDSatcom Meerkat project.
- 0.058 mm RMS mold surf
- 0.090 mm RMS part surf
- Similar results for DVA-2 would be expected.

GDSatcom Secondary
•Part2 RMS 0.101mm
•Part1 RMS 0.098mm
•Mold RMS 0.063mm
•Part/mold 1.6



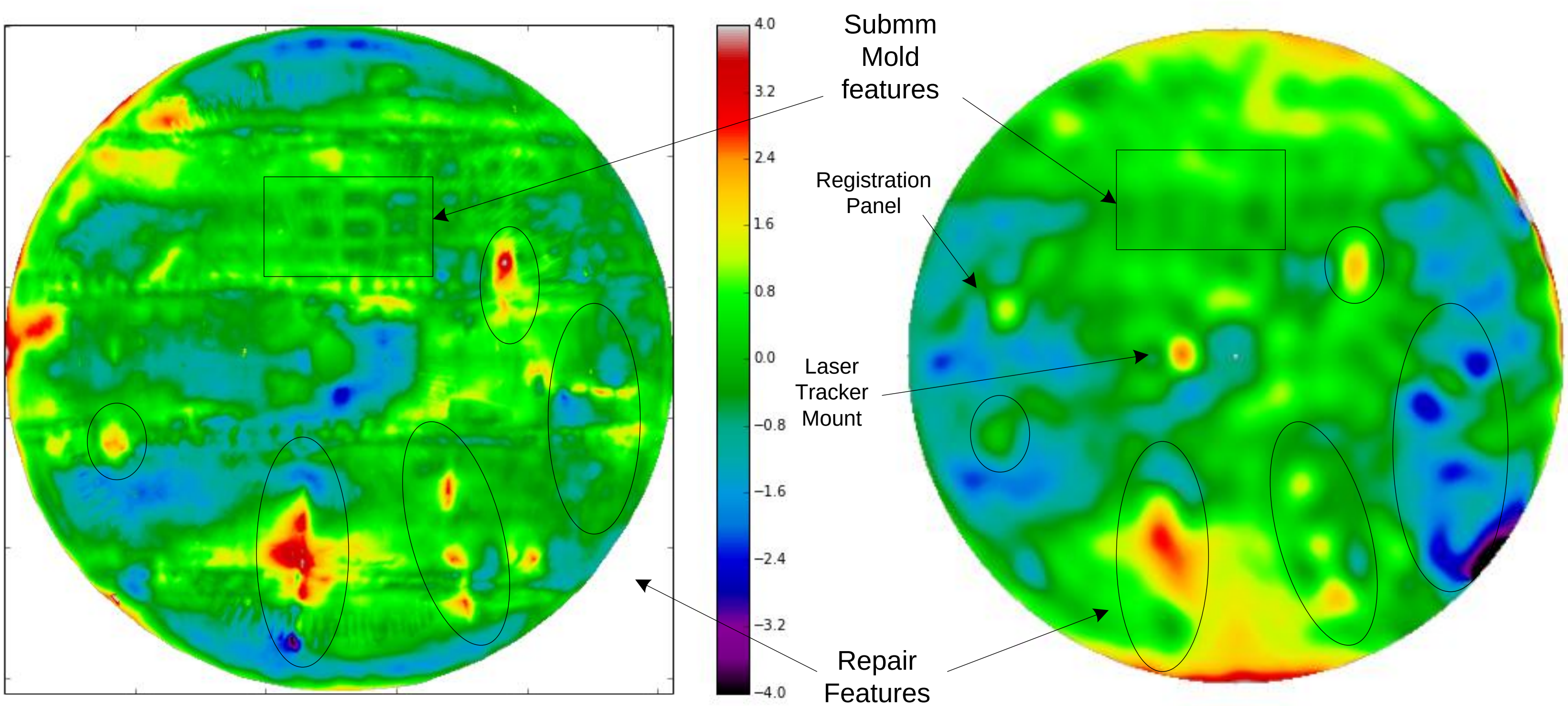
Primary Surface Scan,
Rim Horizontal (Bird Bath).

- Most of surface is within ±1.0mm (green)
- Most red areas are repaired areas, after helicopter transport damage.
- Almost all other features are in the mold surface (horizontal banding, grid feature in upper right quadrant).
- 0.89 mm RMS
- 0.70 mm RMS aperture weighting



Primary Surface

Laser Tracker vs Holography



Demonstrates holography is representing surface very well.

Reflector Temperature Stability

Primary Reflector

Coupon Testing

5.62 μm/m^{o}C

DRAO test August 6th

5.42 ± 1.08 μm/m^{o}C

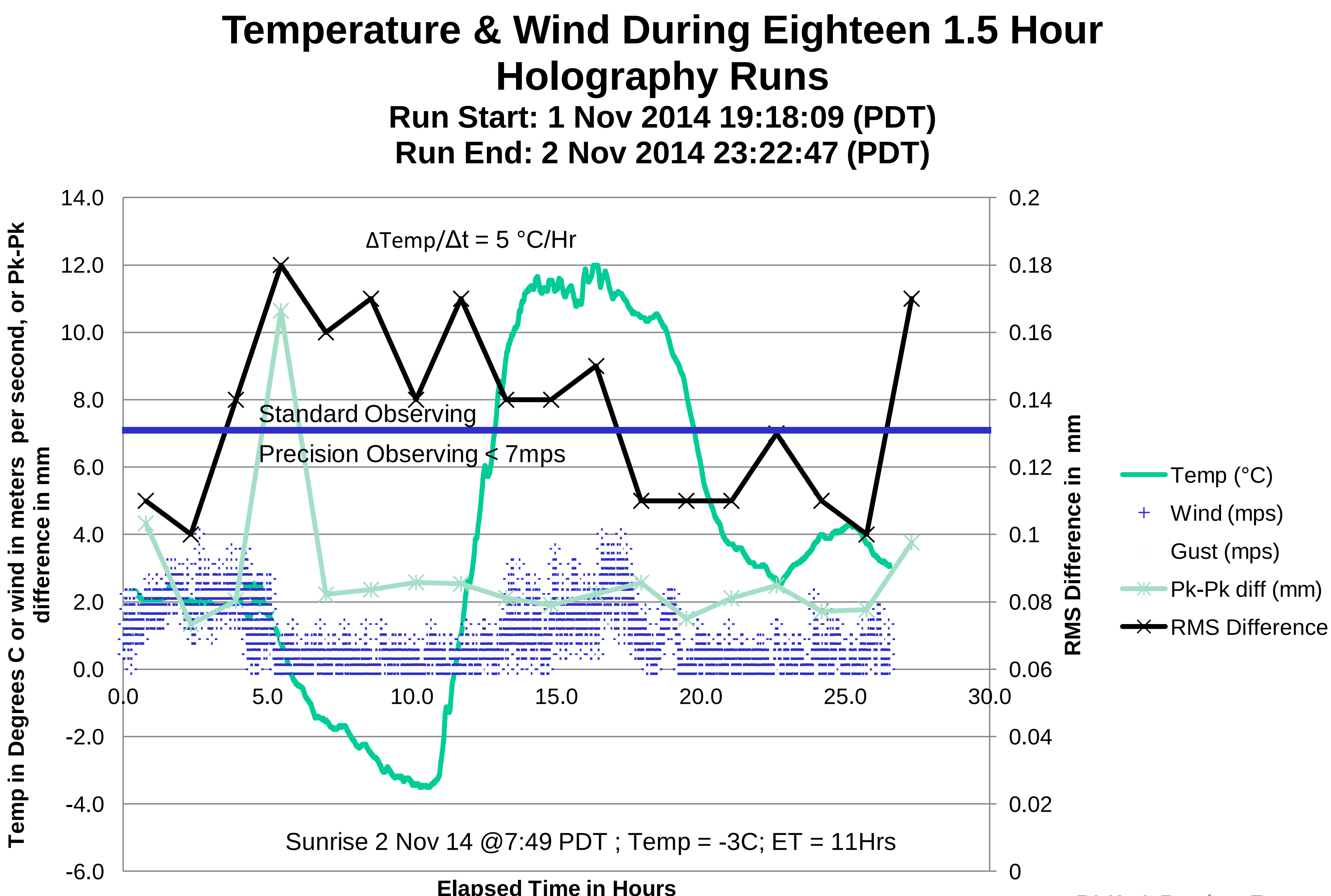
Secondary Reflector (estimated)

3.18 μm/m^{o}C < $CTE_{secondary}$ < 5.62 μm/m^{o}C

Aluminium > 4 times higher 23.6 μm/m^{o}C

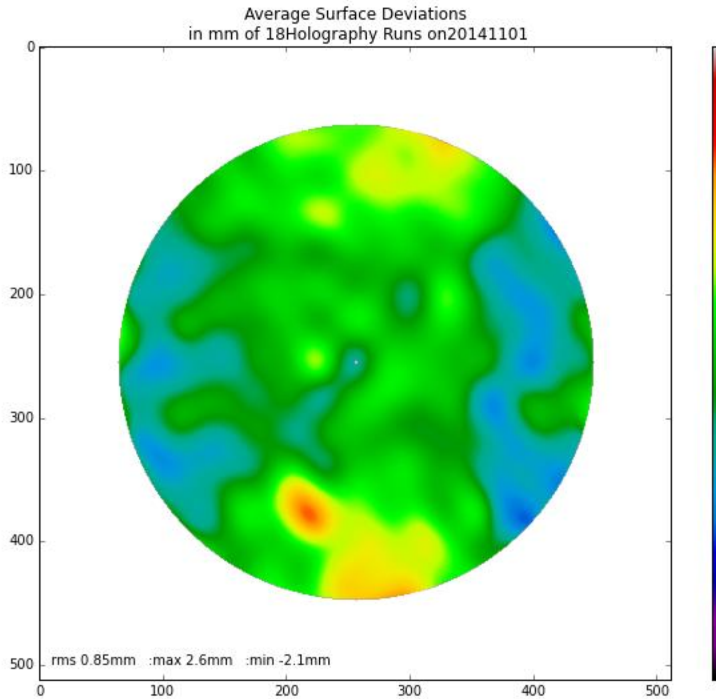
Primary Surface Stability

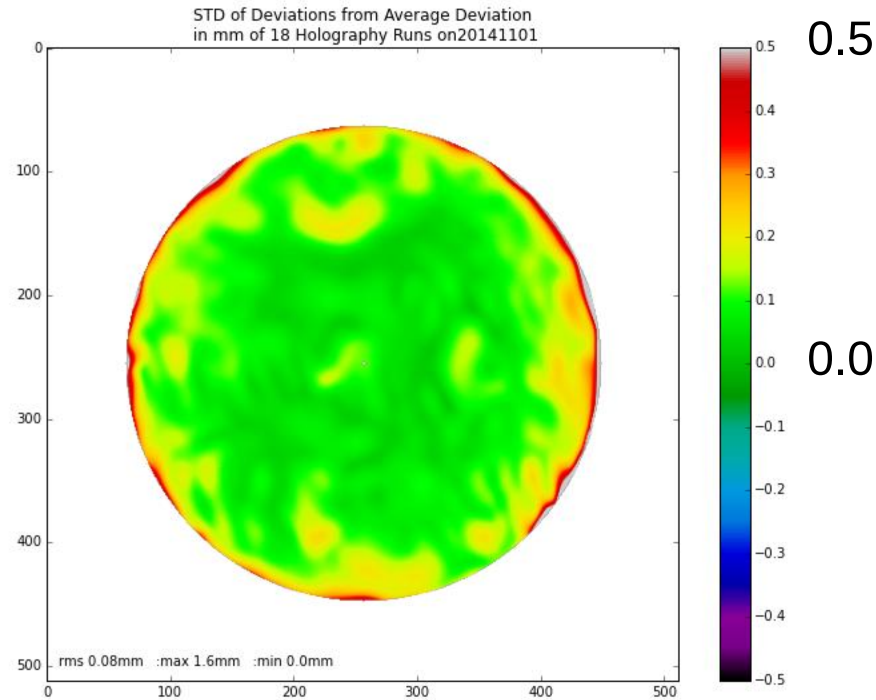
(no correlations, wind or temperature)



Primary Surface Stability

Deviations from Average
18 Holography Maps (28 Hrs)



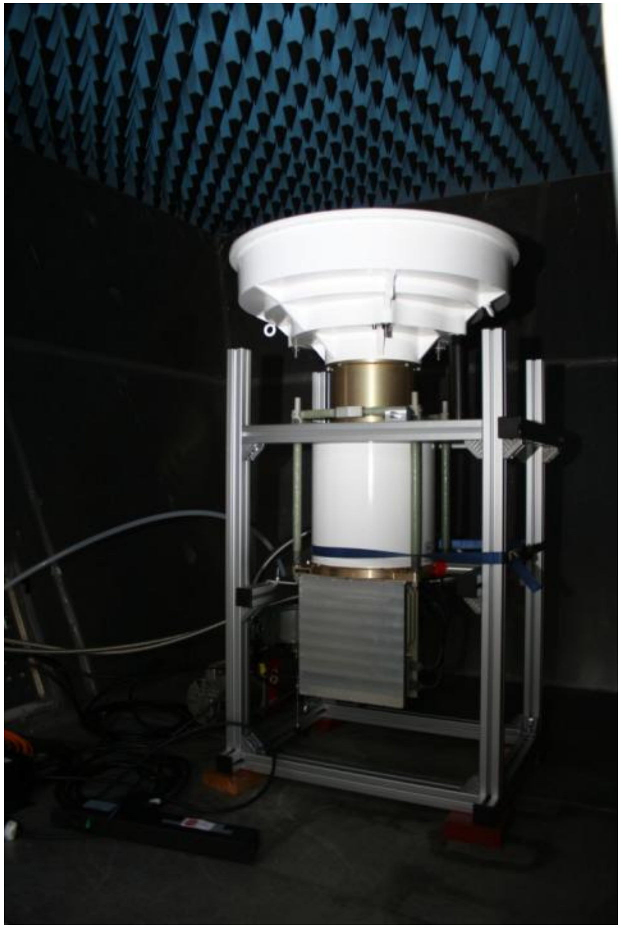


Average Surf Deviations
RMS 0.85mm

Deviations from Average
RMS 0.08mm

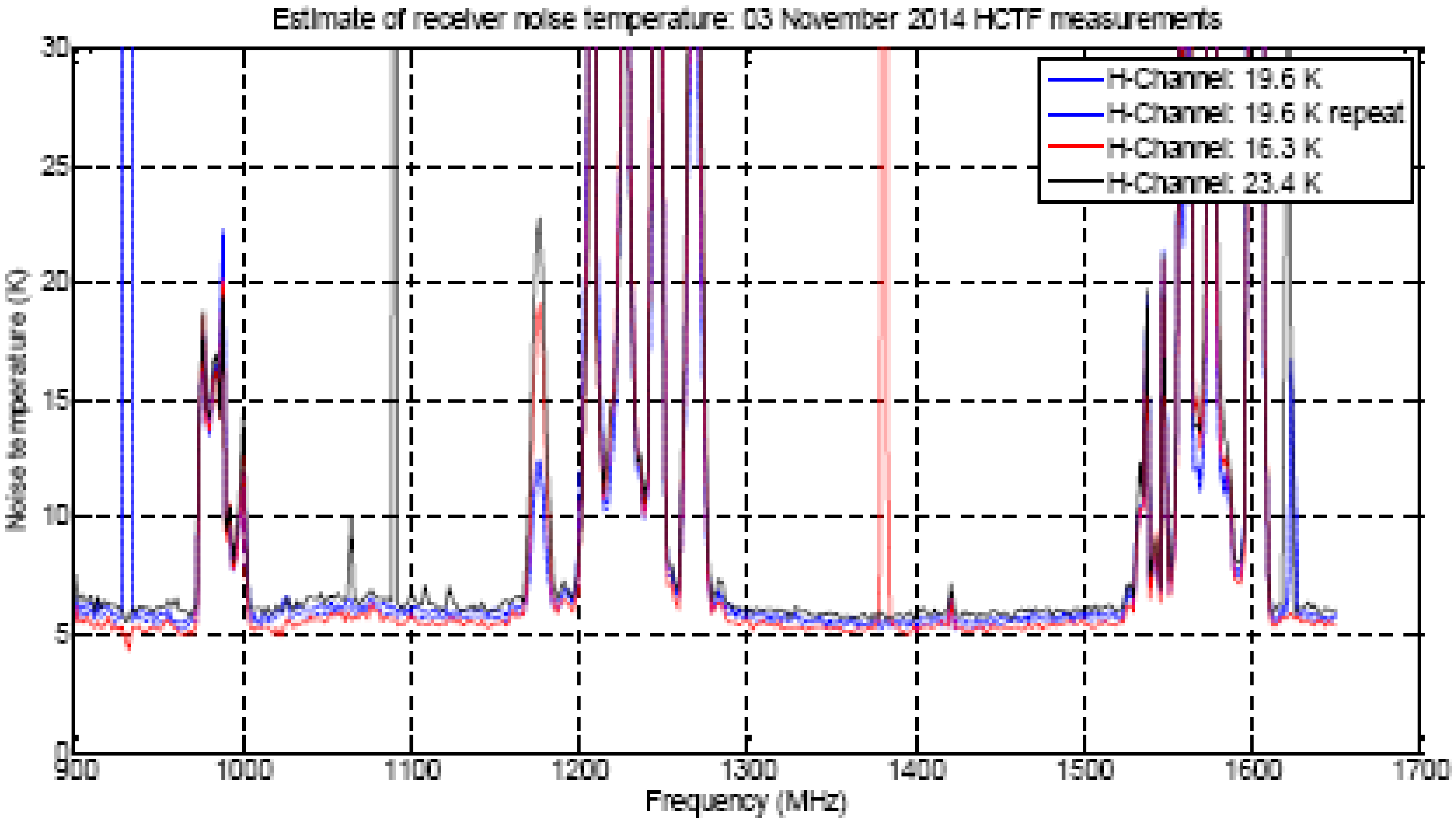
Noise Temperature

Testing the MeerKat Receiver

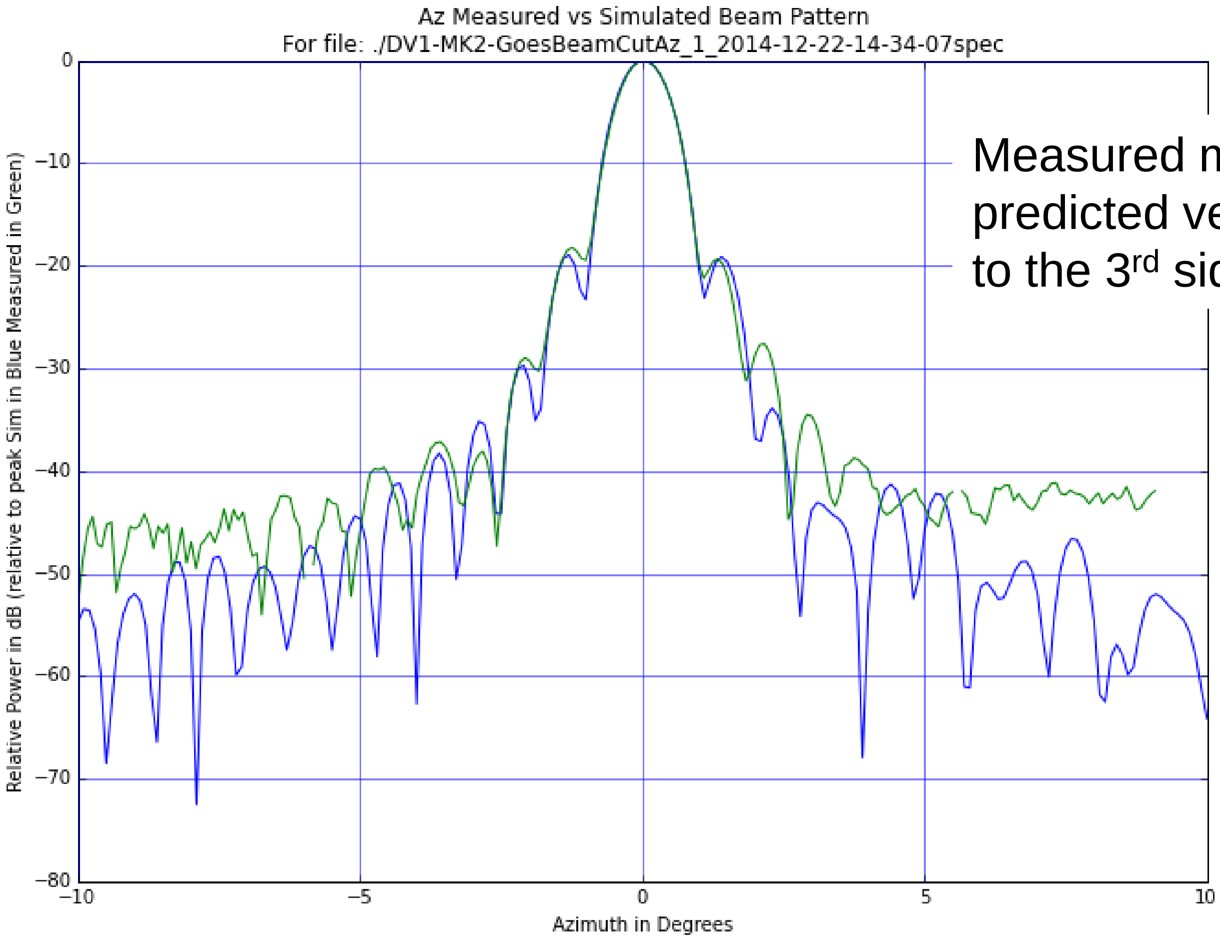


Noise Temperature

EMSS L-Band for MeerKat Receiver



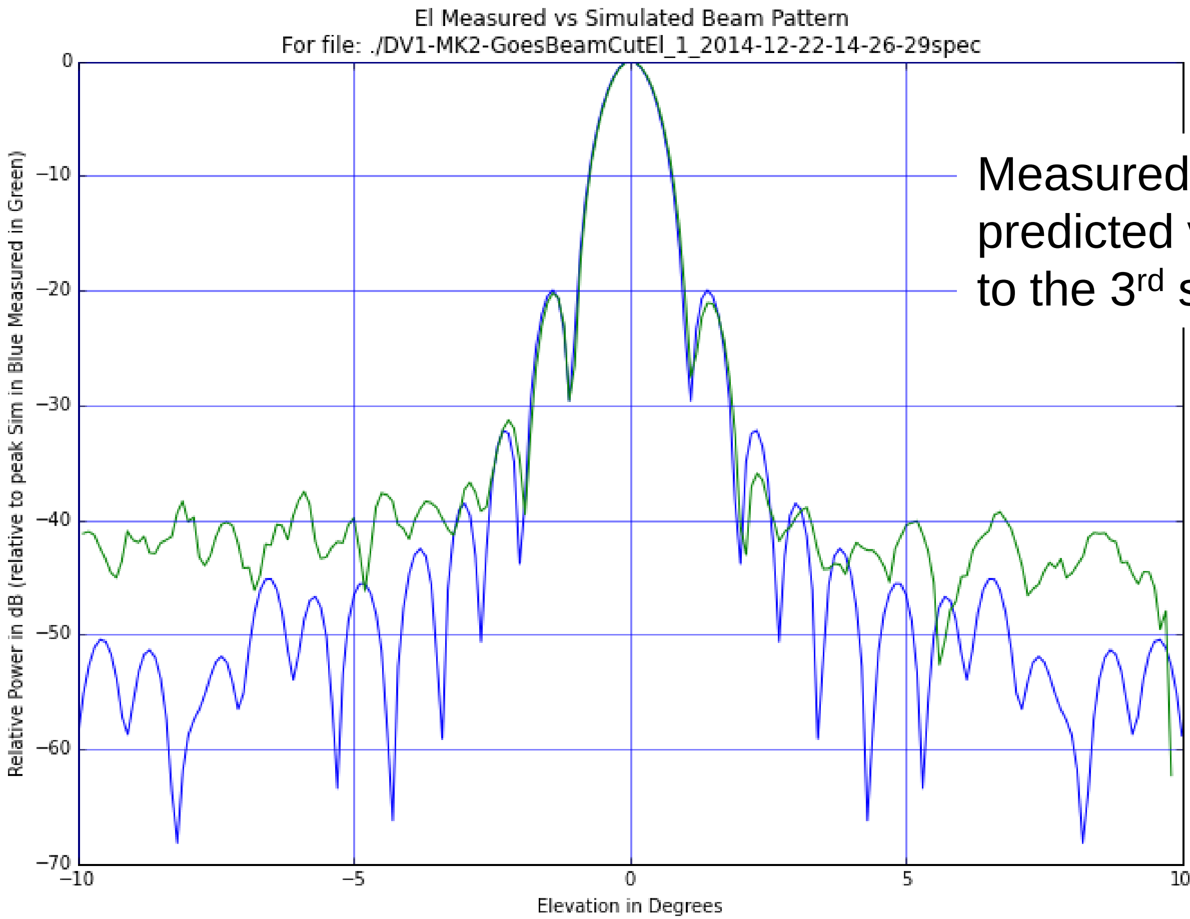
Azimuth Pattern
at 1544.5 MHz (GOES West Satellite)



Measured matches predicted very well to the 3rd side lobe.

Elevation Pattern

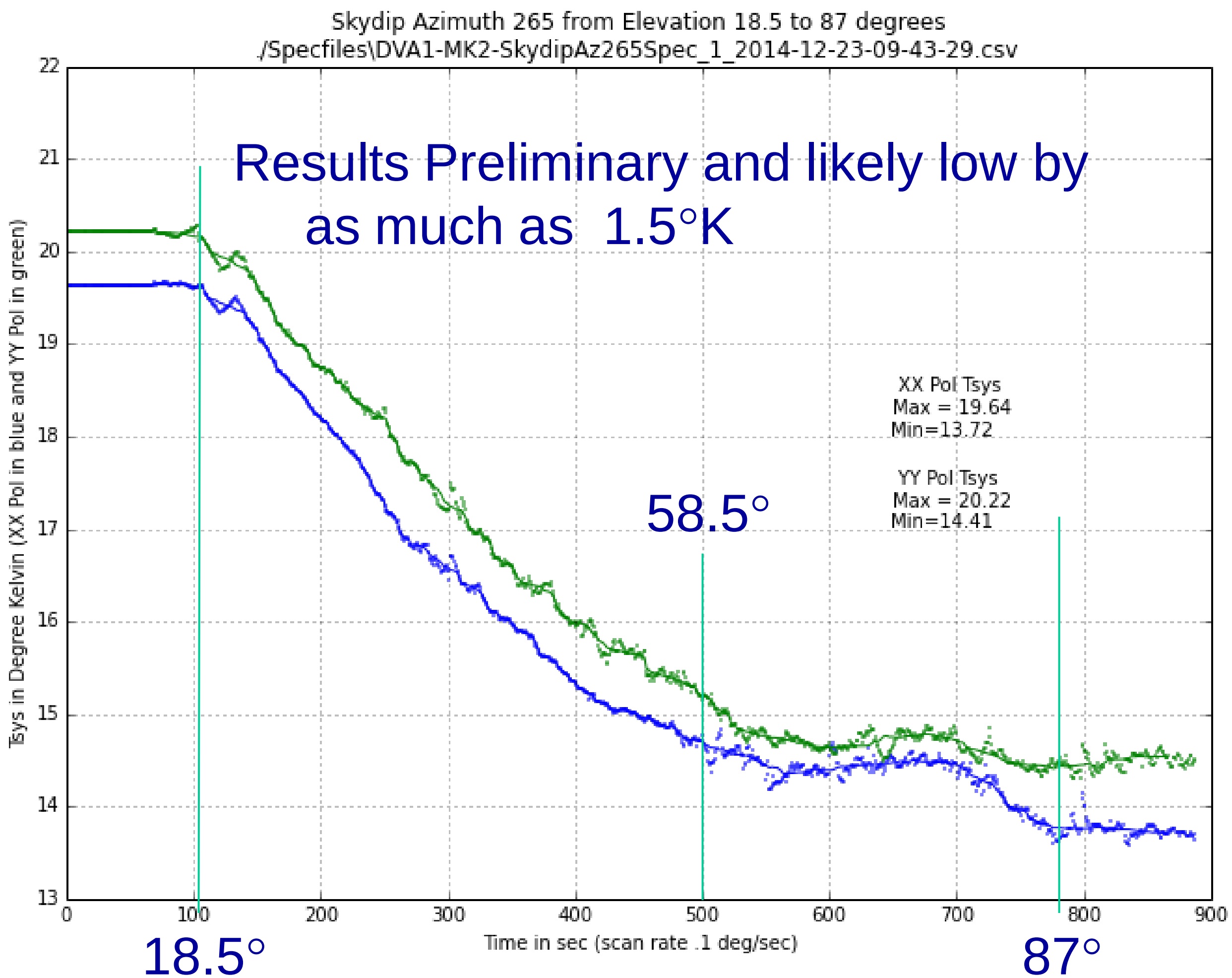
at 1544.5 MHz (GOES West Satellite)



Measured matches predicted very well to the 3rd side lobe.

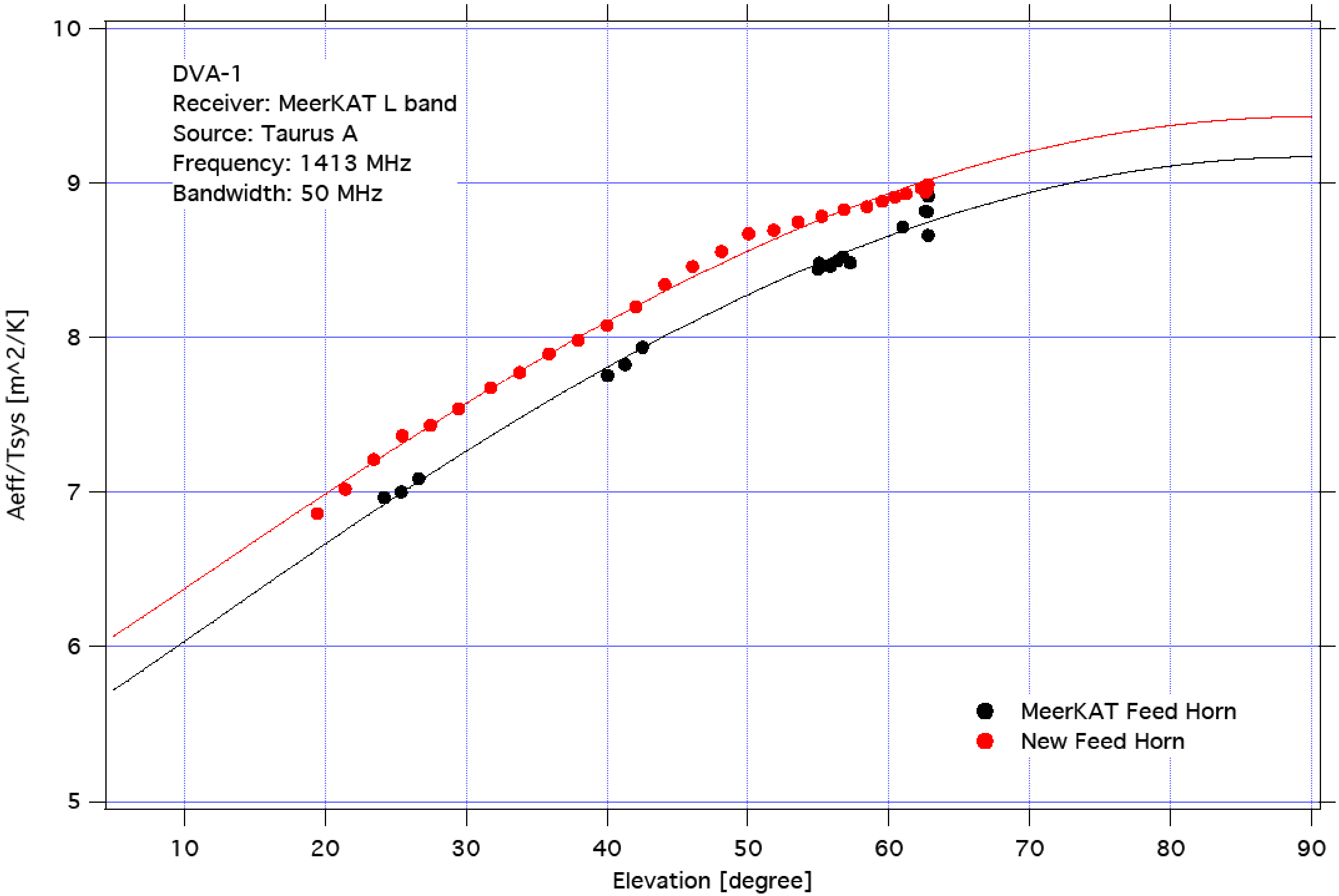
Preliminary Tipping Curves Results

Tsys Kelvin



Antenna Aeff/Tsys

with MeerKat and New (LB) Horn



Issues and Technical Risks

Key retired technical (technology) risks

Composite reflectors meet requirements for

- Reflectivity
- Mechanical and thermal properties
- Surface accuracy

Outstanding risks now very low.

- Majority have been mitigated by simulation/measurement
- Those remaining will be retired by RF testing

DVA-1 Costs

Item	Materials	Labour	Sub-contract	Totals
Reflectors, feed platform and support structures				
Composite Dish Surface, Secondary, Central Reinforcement	$111,000	$63,400		
Composite Backing Pieces, fabrication portion, not including molds			$23,250	
Dish Rim Connector, labour (material in line 3)		$14,000		
Ball studs			$6,132	
PDSS			$84,874	
Feed Platform			$6,700	
Secondary Support Structure			$85,000	
Sub Totals	$111,000	$77,400	$205,956	$394,356
Pedestal Components				
Tower, contract with Minex Engineering			$300,000	
Tower, misc extra parts, package 1			$19,920	
Tower, misc extra parts, package 2			$90,600	
Tower, additional items			$14,836	
Drive system (motors, control system and encoders)			$43,000	
Painting			$5,000	
Sub Totals			$473,356	$473,356
			Grand Total	$867,712

297 lbs / sq-m
121 kg / sq-m
4,520 $/sq-m

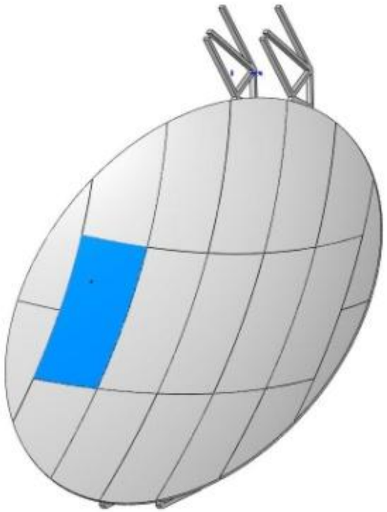
Comments for Future Antennas

A single piece composite reflector may achieve the cost objective if the antenna diameter can be kept smaller.

If a single piece reflector will not achieve the specification, consider rectangular panels supported on a space frame type of structure. There is no reason to use pie segments in high volume production.

If the dish diameter becomes large and the pointing spec demanding, consider wheel and track with new metrology applied.

Accurate wind tunnel data for an offset design is needed.



Questions?

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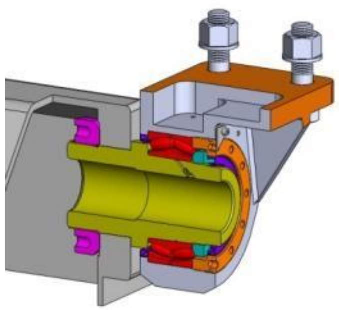
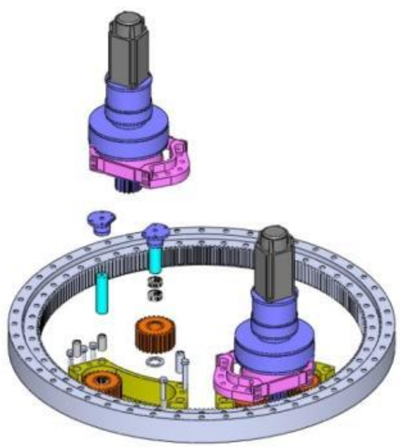
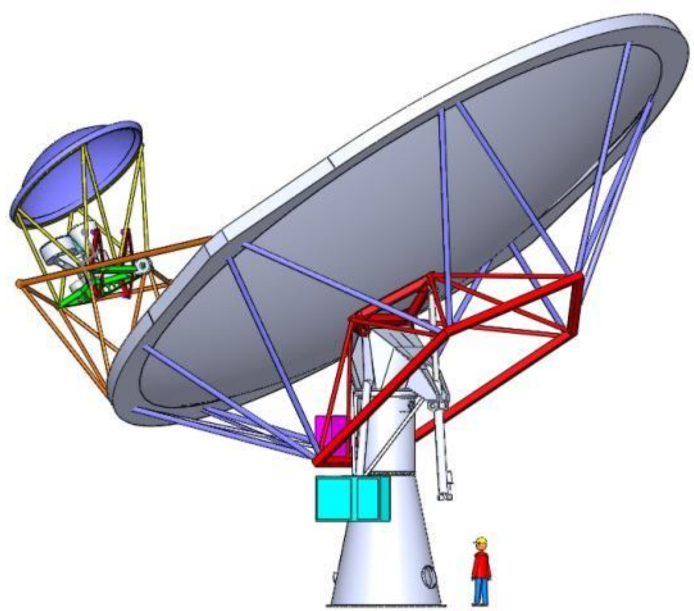
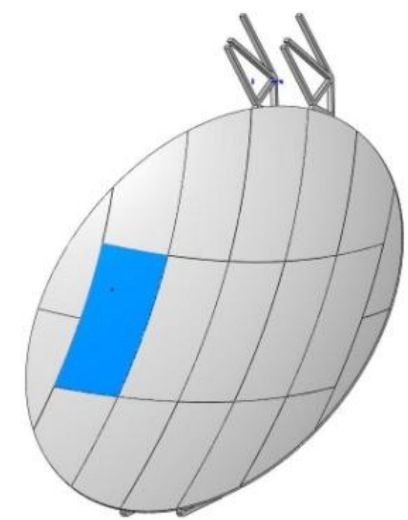
Extra Slide Discussion Topics









Extra Slide

Mold & Part Accuracy

Summary of measured data for molds and reflectors:

DVA1 prmry mold: 0.47 uniform weight, 0.39 amplitude weight

DVA1 prmry part: 0.89 uniform weight, 0.77 amplitude weight

DVA1 prmry part: 0.69 uniform weight, clipped at 1.5 mm., 9% of points dropped: (drops data from the worst damage spots only)

DVA1 scndry mold: 0.12 uniform weight, 0.11 amplitude weight

DVA1 scndry part: 0.20 uniform weight, 0.16 amplitude weight

DVA2 prmry mold: 0.20 uniform weight, with new high tol mold.

Full Antenna Assembly