Metrology Plan and Quality Engineering for Canadian Hydrogen Observatory for Radio-transient Detector (CHORD) Antennas

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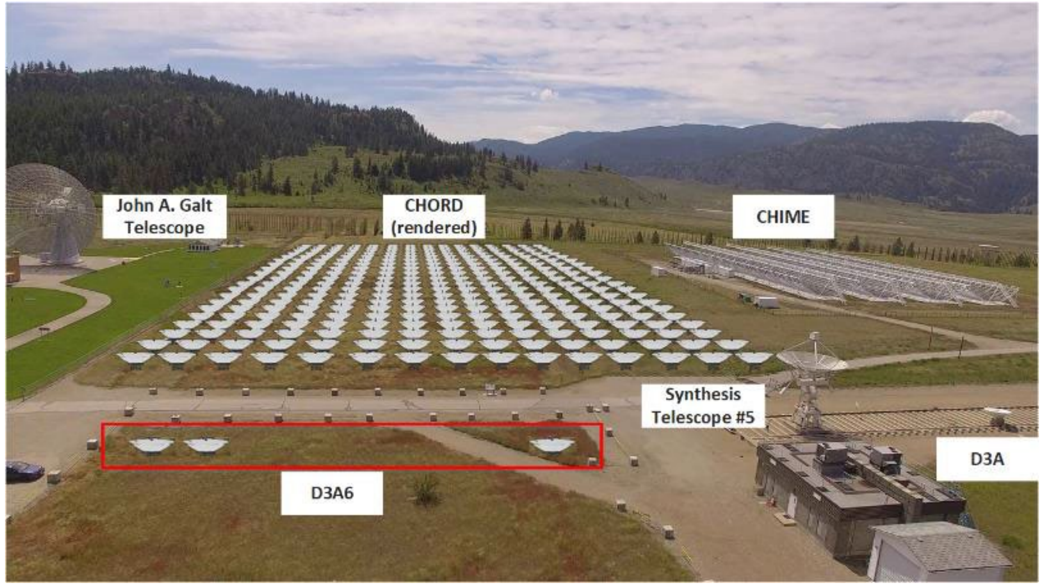
Topics

- CHORD description
- Top level requirements
- Antenna errors/ Telescope errors
- Antenna verification plan
- Antenna alignment plan

CHORD Project

CHORD

CHORD Site



Looking south

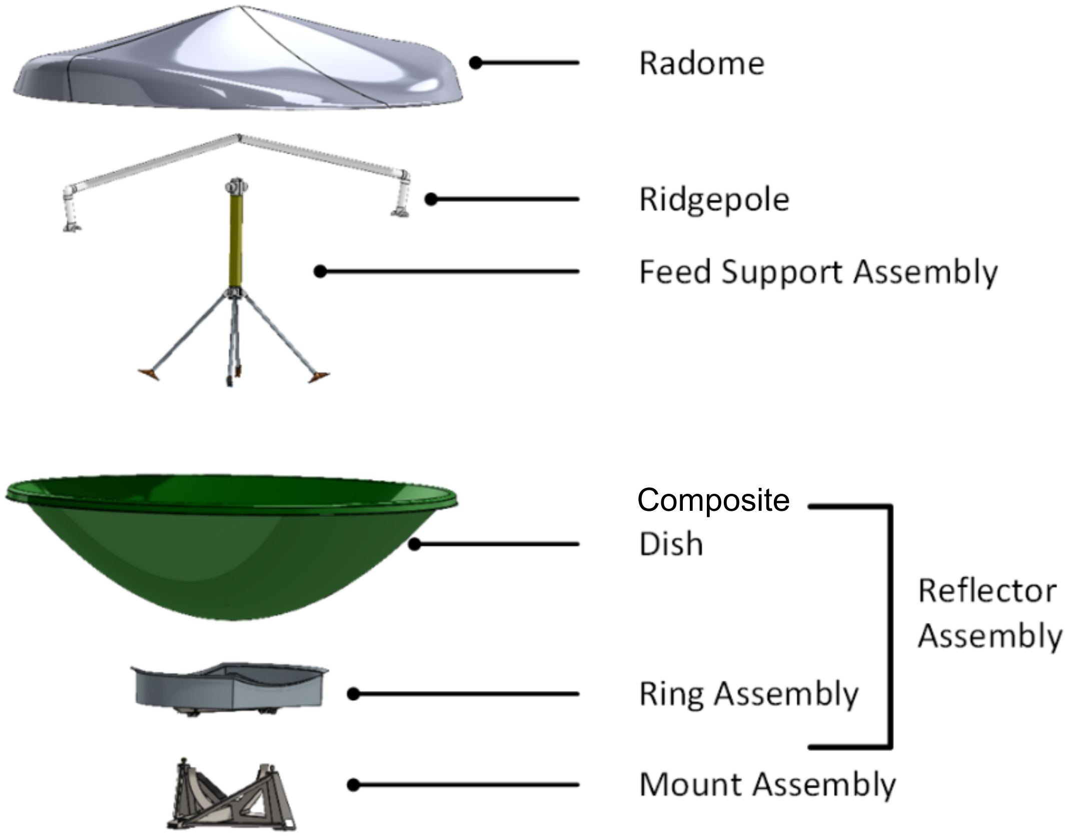
220 m N-S
160 m E-W
512 antennas

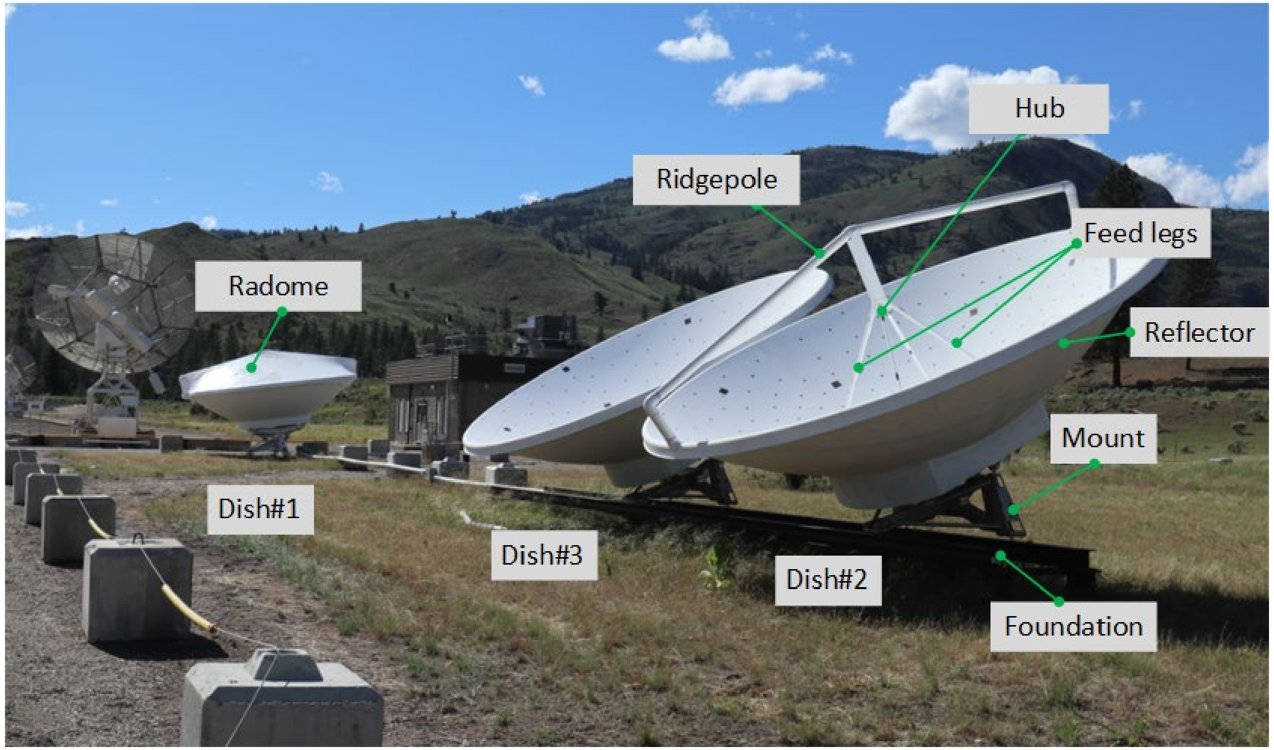
CHORD Antennas

- Prototype antennas were built
  - Two 3m D3A antennas
  - Three 6m D3A6 antennas
- 6m composite reflectors, stainless steel base – total 512 (core) + 140 (outrigger)
- Production process is tested
- Currently setting up production factory
- Currently finalizing the verification plan
- Need feedback on the metrology plan

CHORD Antenna Prototype

Antenna





CHORD Prototype - D3A6

Top level Antenna Requirements

Requirements

- F/D ratio: 0.21
- Elevation range : $\pm 30°$
- Local drive system, inclinometer will be used to get the pointing
- Meet DRAO environmental conditions

- Array pointing accuracy: 13.5 arc min (mean)
- Array pointing precision: 1 arc min RMS (standard deviation)

- Frequecny range : 300 MHz to 1500 MHz
- Antenna surface error < 1.2 mm RMS under normal conditions
- Feed movement, elevation center error, elevation axis placement error etc.

Surface Requirements

Antenna surfaces – 512 antennas

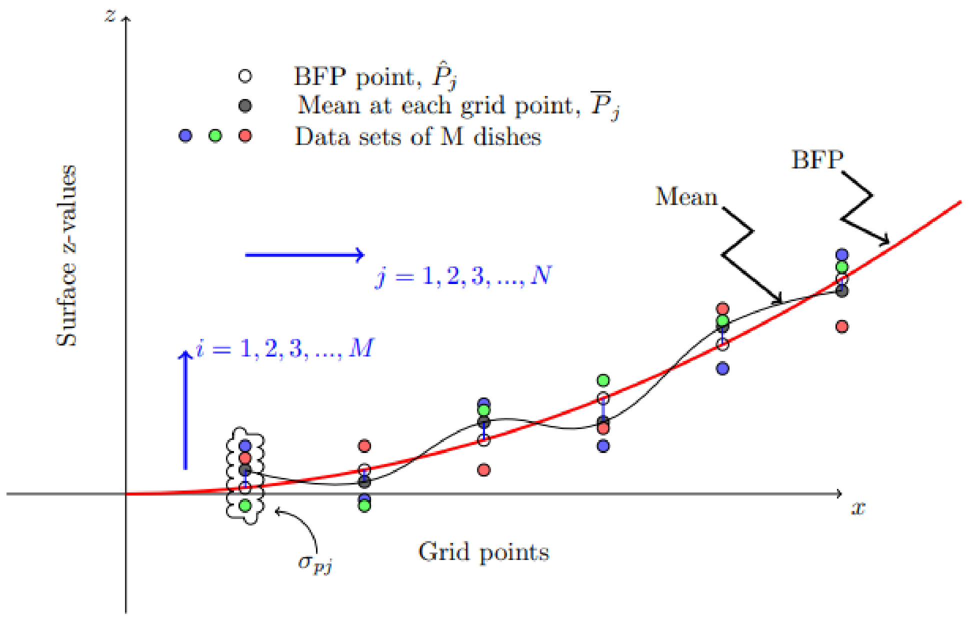
- Accuracy < 0.8 mm RMS (mean)
- Precision < 0.2 mm (definition: TBD)

Mold surfaces – 4 molds

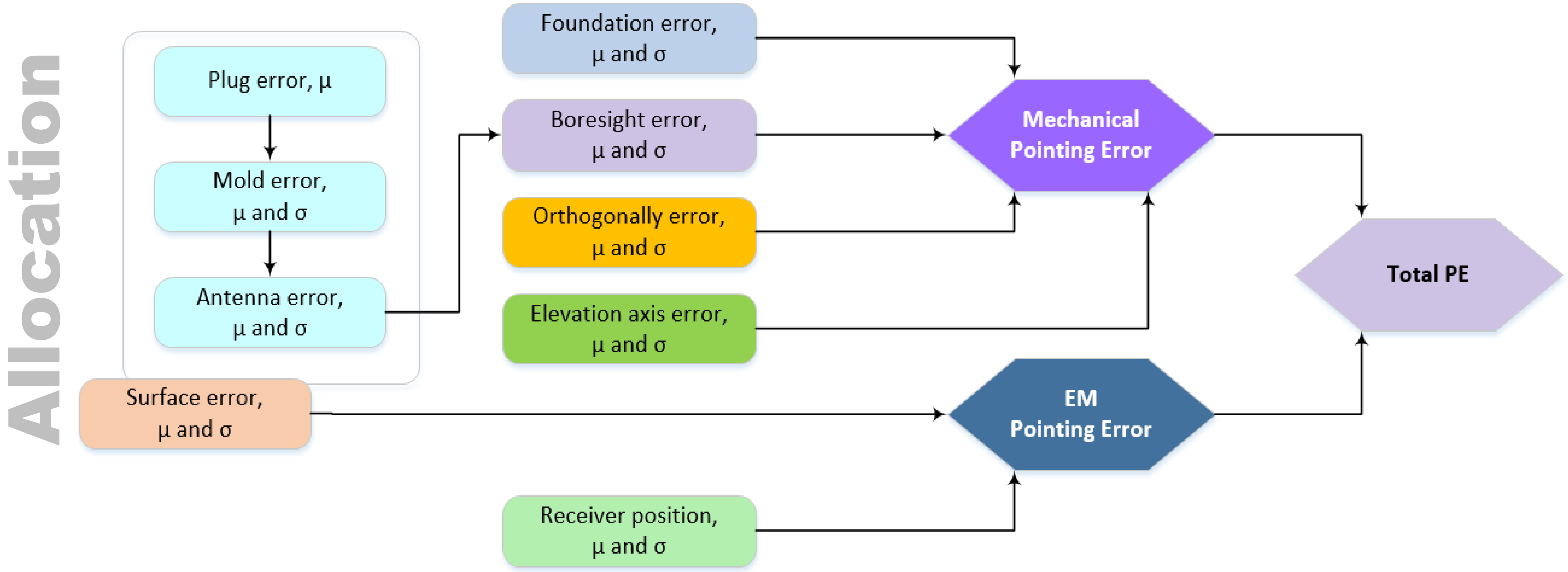
- Accuracy < 0.5 mm RMS (mean)
- Precision < 0.1 mm (definition : TBD)

Plug surface

- Accuracy < 0.300 mm RMS

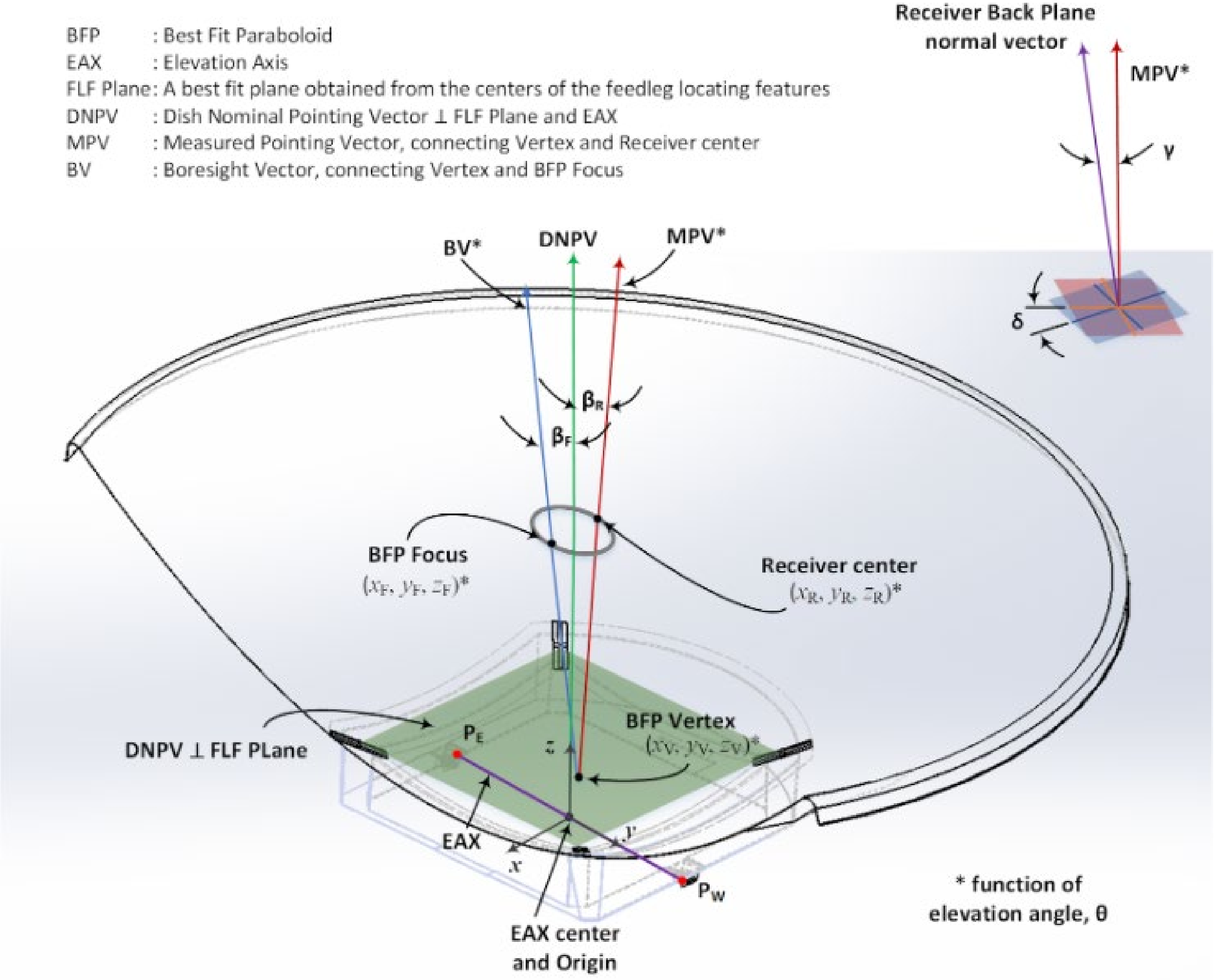


Pointing Error Contributions



What are the Antenna Errors?

Antenna Errors

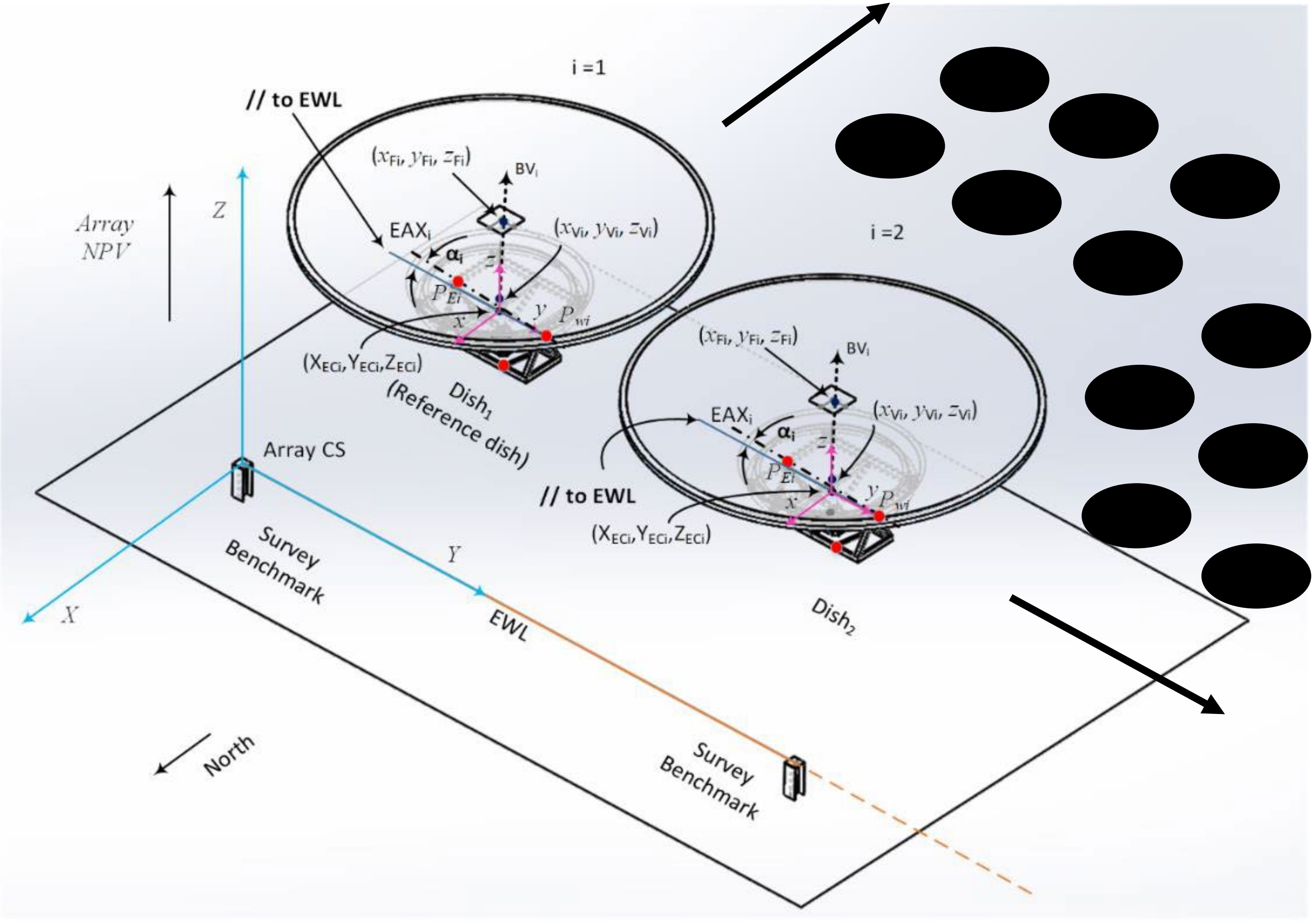


Definitions

a. The Elevation Axis (EAX) points, P_E and P_W constructs the EAX as well as the y-axis in the dish coordinate system. The (+ve) y-axis direction lies from P_E to P_W. The EAX center is defined as the midpoint of the EAX and also the origin of the Antenna CS.
b. The +ve z-axis is perpendicular to the elevation axis when the dish is pointing at zenith. The z-axis also coincides with the Dish Nominal Pointing Vector (DNPV). The Dish NPV passes through the elevation axis center and is perpendicular to the Feedleg Locating Feature (FLF) Plane. The FLF Plane is a best fit plane through the FLF cross centers.
c. In the dish coordinate system, the BFP vertex is presented as (x_V,y_V,z_V). The BFP focus and receiver center are presented as (x_F,y_F,z_F) and (x_R,y_R,z_R) respectively.
d. The Boresight Vector (BV) is defined as the vector connecting the Best-fit-Paraboloid (BFP) vertex to the BFP focus of the dish. The BV will be oriented with the elevation angle.
e. The Measured Pointing Vector (MPV) is defined as the vector connecting the BFP vertex to the measured receiver center. The MPV will be oriented with the elevation angle.

What are the Alignment errors?

Alignment Errors

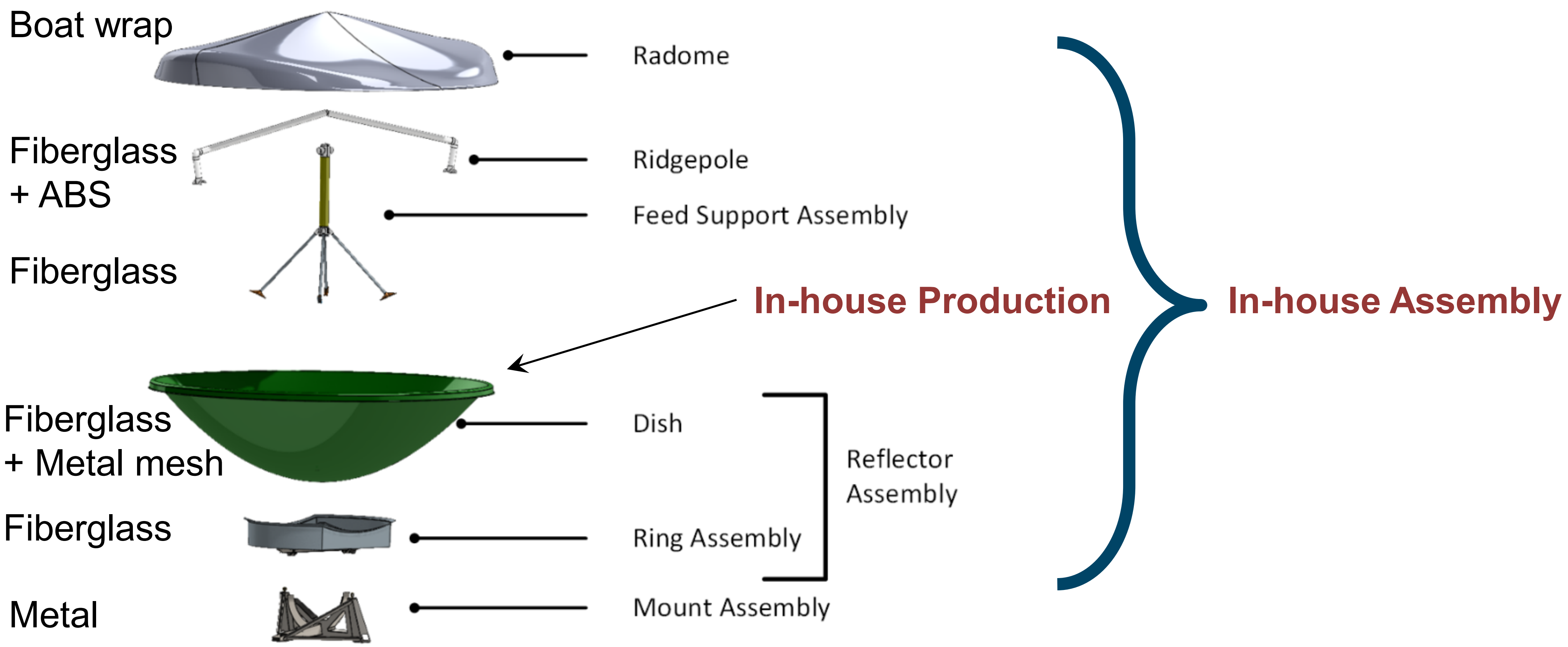


F

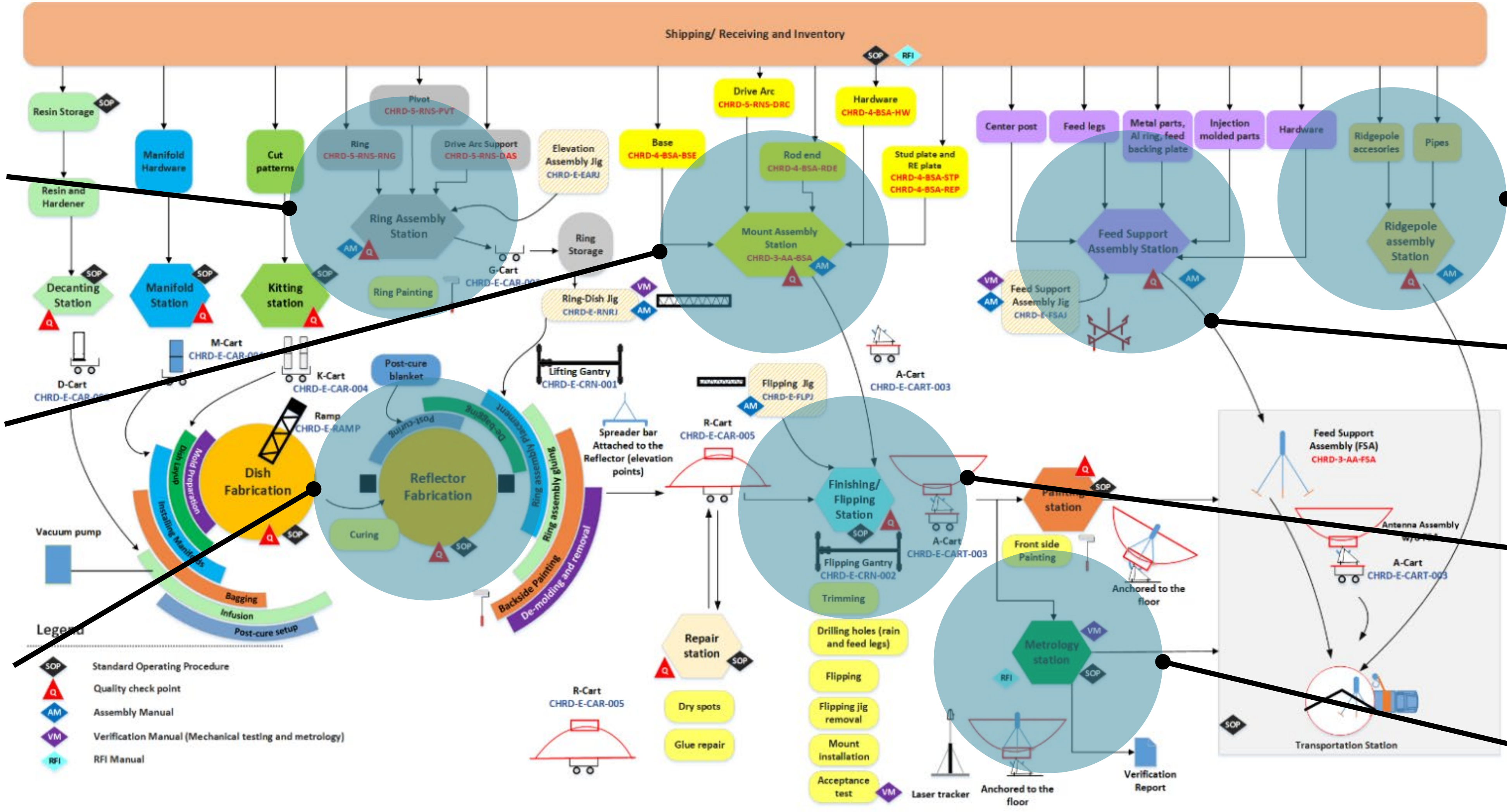
East-west (EW) line definition
- Two screw piles will define the astronomical east-west line as reference

Primary goal
- Align each antenna to the EW line
- Meeting antenna elevation axis alignment precision < 0.5 arc minute
- Meeting antenna elevation axis alignment accuracy < 2.5 arc minute

CHORD antenna anatomy - revisit



Production System Block Diagram



Ring Assembly Station

Mount Assembly Station

Reflector Fabrication Station

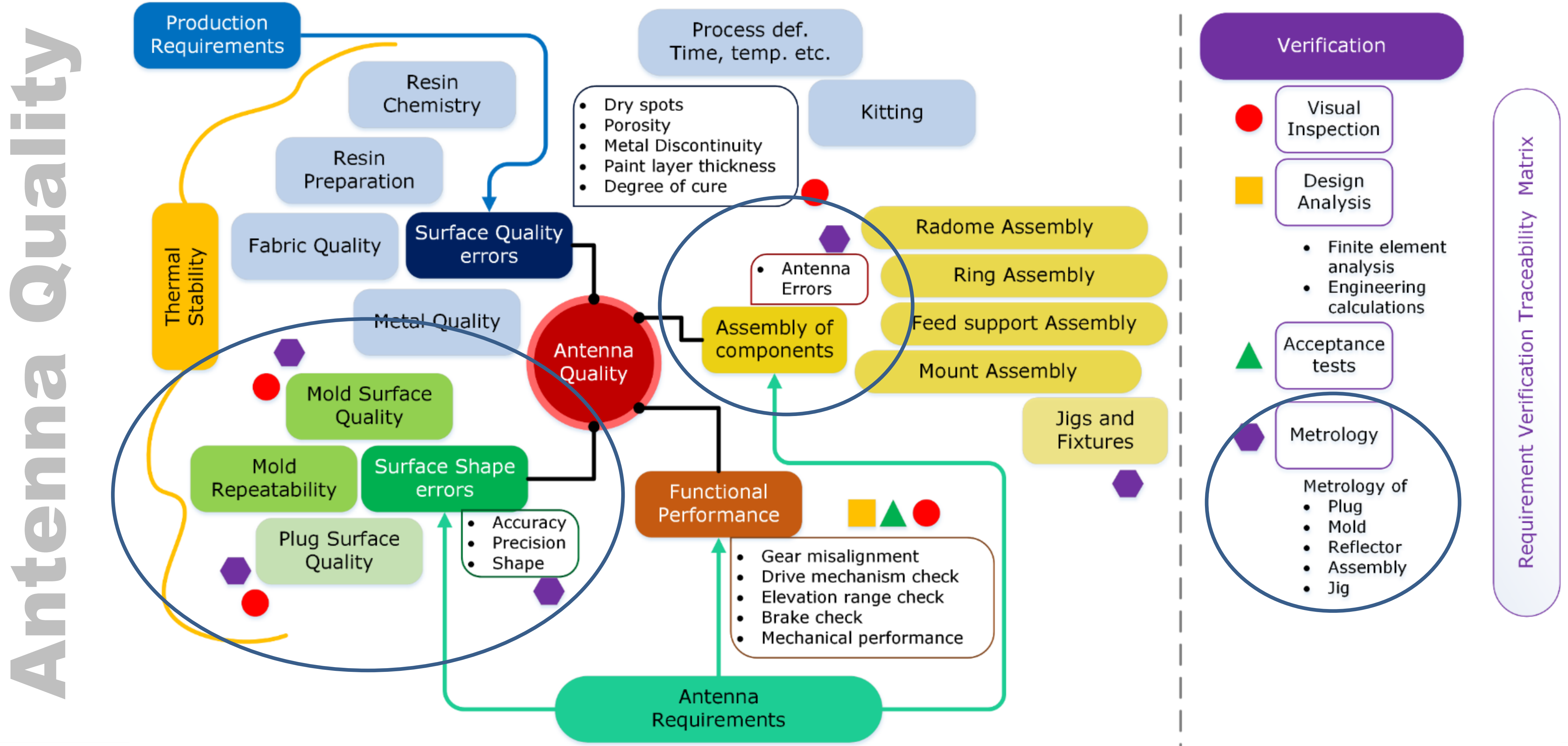
Ridgepole assembly Station

Feed Support Assembly Station

Flipping/ Finishing Station

Metrology Station

Antenna Quality, Requirements and Verification



Verification (Metrology setup)

Verification

- FARO tracker (indoor)
  - Accuracy - 20 micron + 5 micron/m
  - Over 5m, measurement uncertainty is 45 micron

Image credit: Brunson

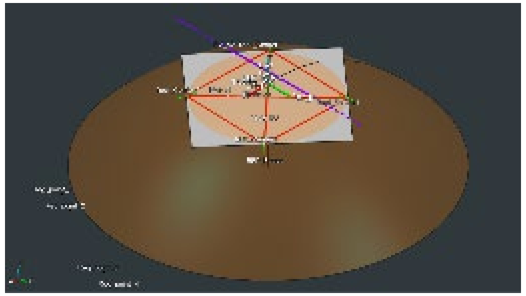
Stand

Laser Tracker

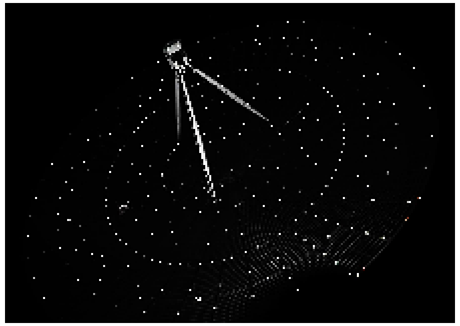
Image credit: FARO

SMR

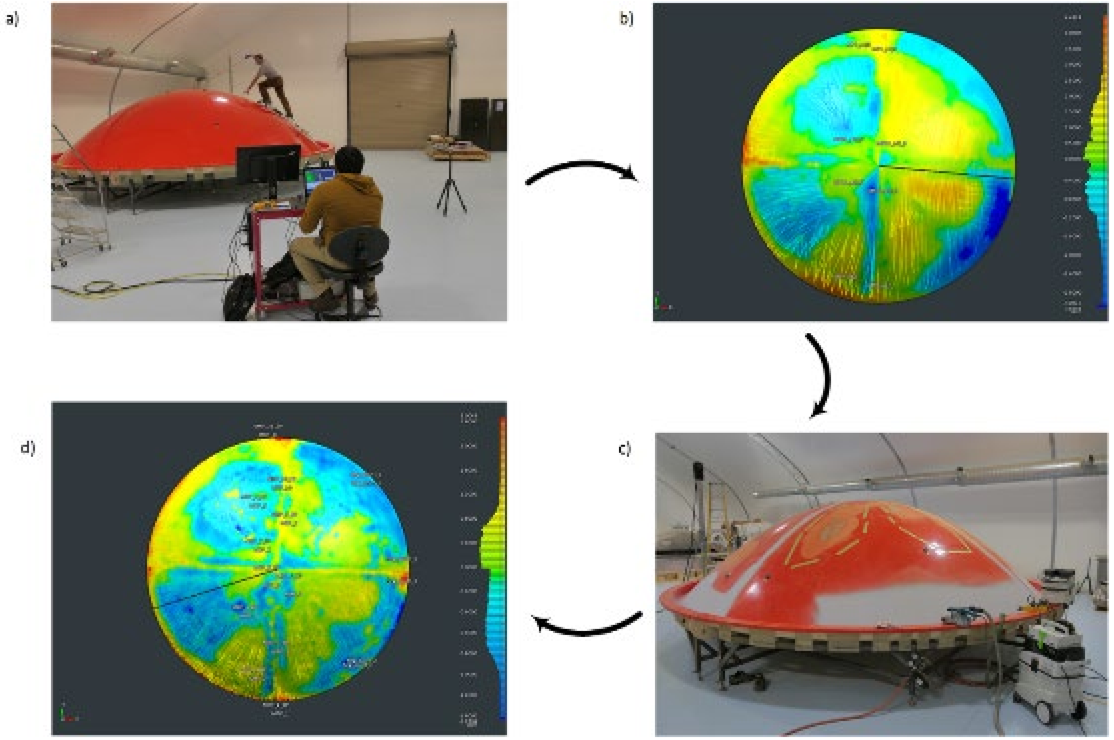
Image credit: Leica



BuildIT



Photogrammetry

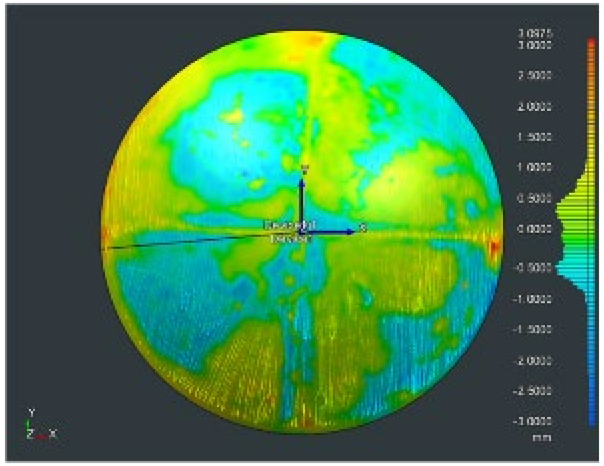


NRC·CNRC

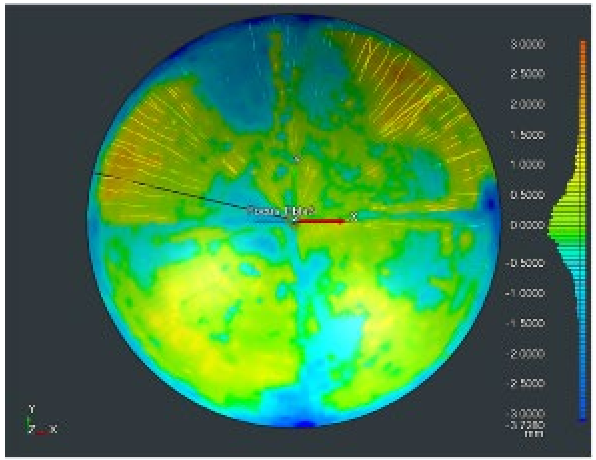
Surface verification – CHORD prototype

Verification

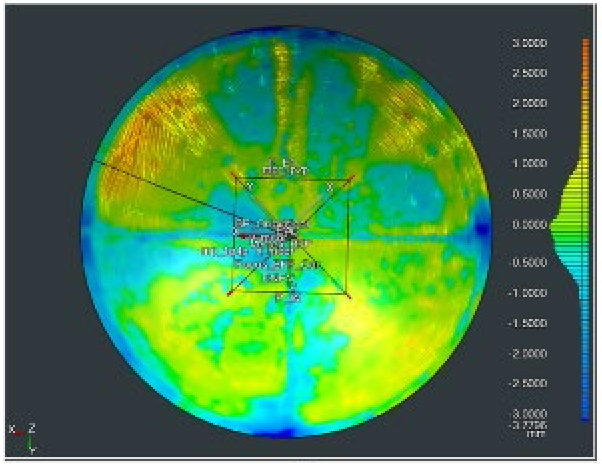
- CHORD prototype (3 antennas) results from a cheap mold
  - ~ 0.675 mm RMS (mean of 3 antenna surface errors)



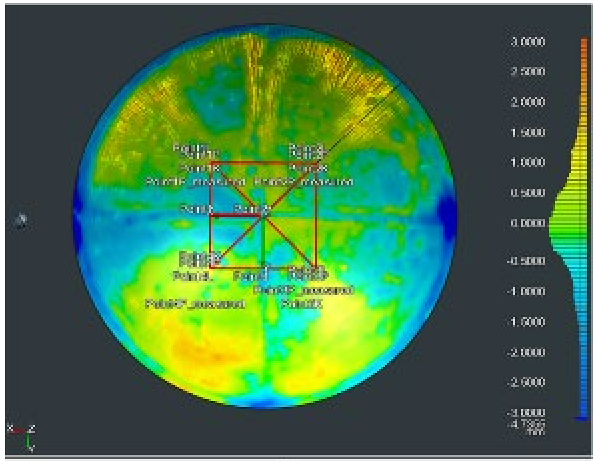
Mold (a)



Antenna 1 (b)



Antenna 2 (c)

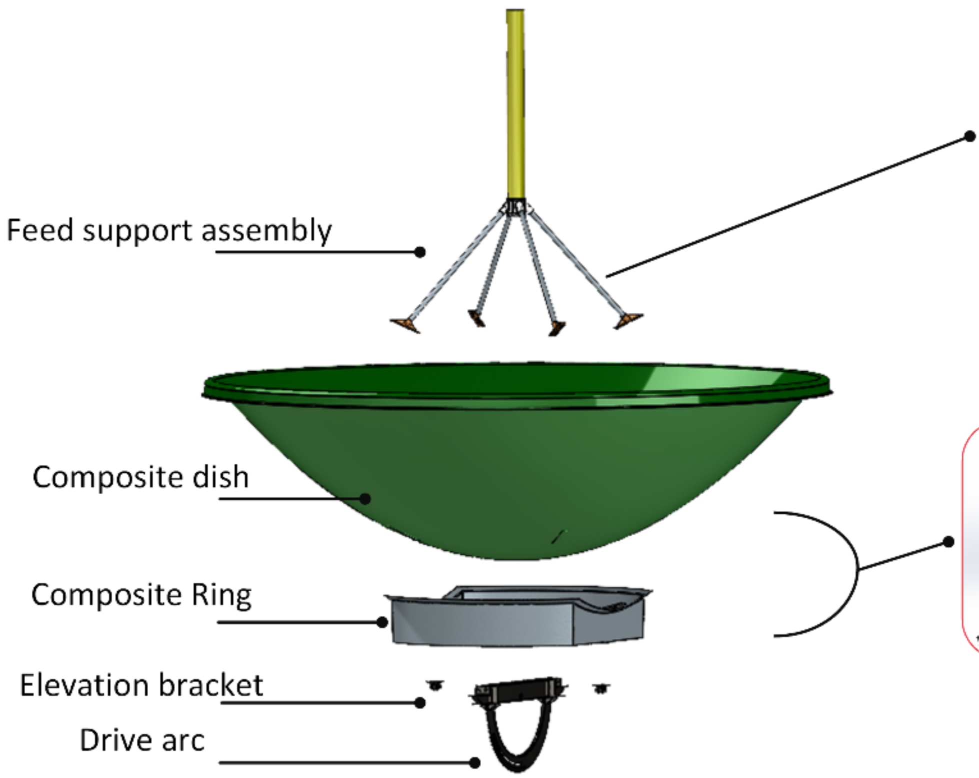


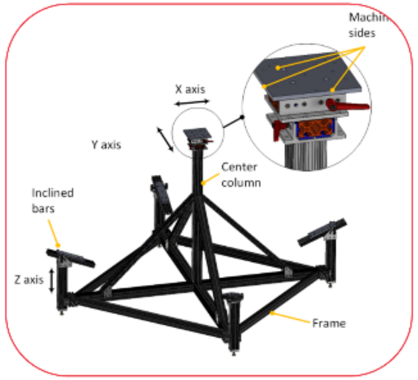
Antenna 3 (d)

Antenna Assembly Verification

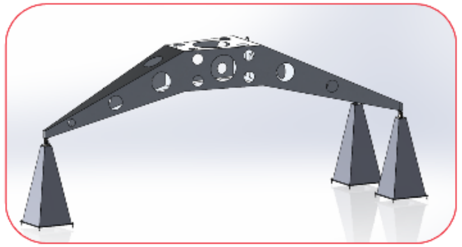
Verification

- Ring defines the elevation axis points
- Ring to Dish assembly
  - Use a jig for repeatability
  - Jig will be adjusted using a laser tracker
  - Related errors: EAX ⊥ to BV, EAC from vertex, inclinometer plane
- Feed support structure to the Reflector
  - Use a jig for repeatability
  - Jig will be adjusted using a laser tracker (target 3D error < 0.5 mm)
  - Related errors: receiver center from focus, receiver orientation





Feed Support Assembly Jig



Dish-Ring Jig

Requirement Verification Traceability Matrix for CHORD prototype

Verification

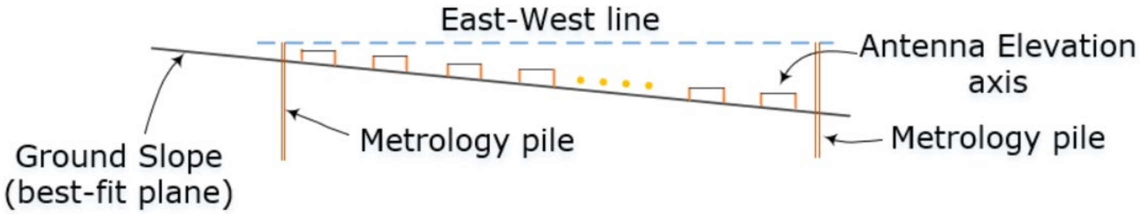
#	Requirement description	Symbols	Status	Requirement values		Dish 1 (Measured)	Dish 2 (Measured)	Dish 3 (Measured)
				Accuracy	Precision			
1	Mold surface error		Resolved	0.55		0.53	0.55	0.55
2	Dish surface error (unpainted)		Resolved	1.2	0.2	0.611	0.643	0.7775
3	f/D ratio		Resolved	0.25				
4	EAX error in the Array	α	Needs Verification	2.5	0.5	0.006	0.2	0.5
5	BFP Vertex and EAX center error, mag (Δx, Δy and Δz are added by quadrature sum)		Needs Verification	3	0.5	1.2	1	0.8
7	Collinearity of the Foci in the Array	ΔXFi	Needs Verification		2	0	10.5	8.06
		ΔYFi			2	-1.11	-1.08	3
		ΔZFi			3 (from BF plane)	3.3	0.57	-0.0428
8	Receiver Back Plane normal offset	γ	Needs to relax	5	1.3	37.35	4.29	8.78
9	Receiver Back Plane Clocking error	δ	Needs Verification	7.5	2.5	25.8	64.2	64.8
10	Receiver center error, Measured from BFP Focus	x_r	Needs Verification		0.25	2.4	0.36	-6.3
		y_r			0.25	0.26	-0.68	-1.3
		z_r			0.25	1.6	0.11	0.2
11	EAX Center in the Array, EC	$\Delta X(EAC)$	Needs Verification	3	1	0.0806	0.1331	0.1421
		$\Delta Y(EAC)$		3	1	-2.414	-5.6939	-1.3236

NRC·CNRC

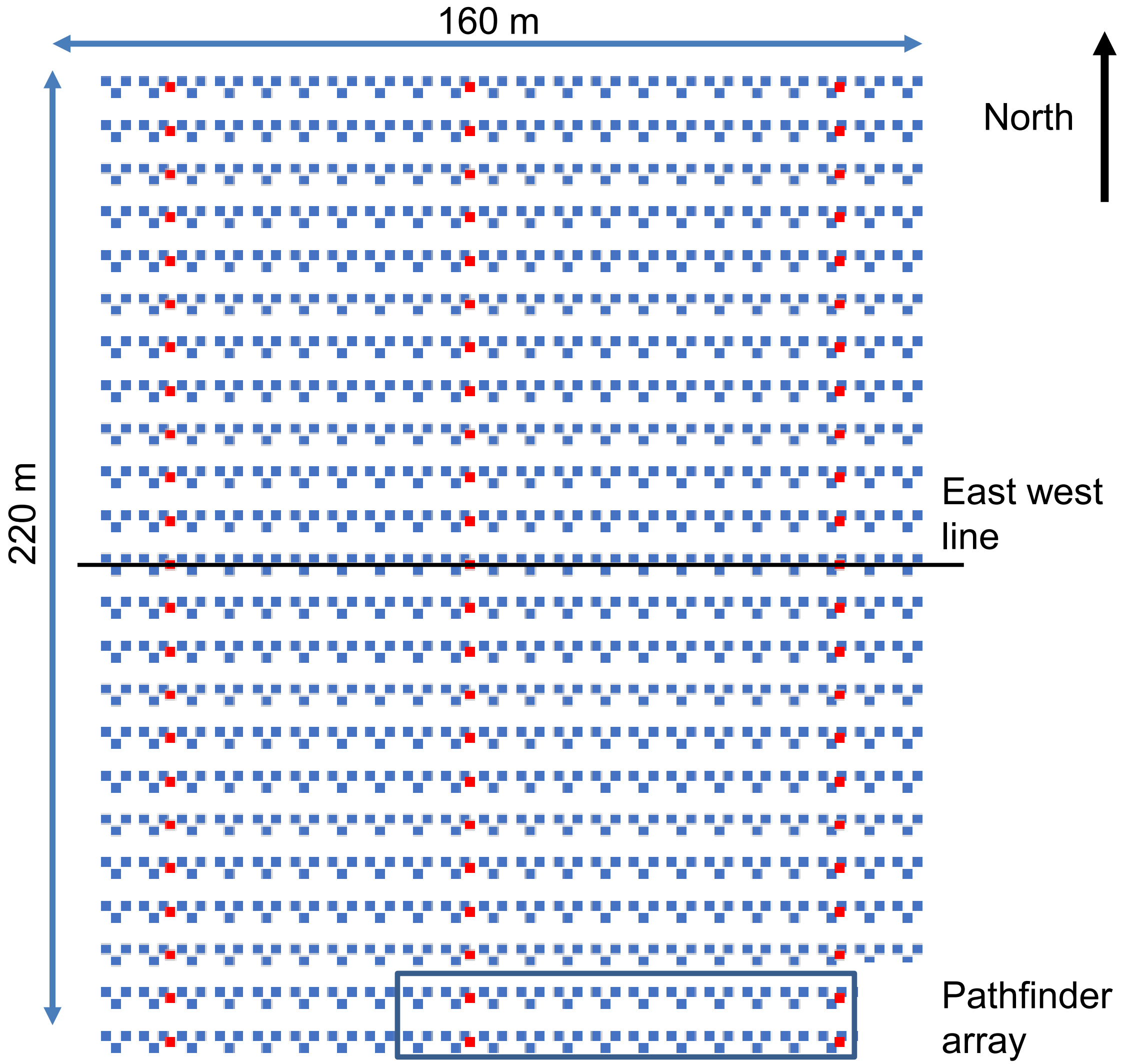
Alignment process of the Antennas

Alignment

- The antennas will be fabricated over a period of 4 years, so does the completion of the alignment of the antennas in the array
- Foundation piles (blue): 3 point ~12' - 15' screw piles with interface plates and studs for mounting the base
- Metrology piles (red): there will be 3 metrology piles with nest holes in each row

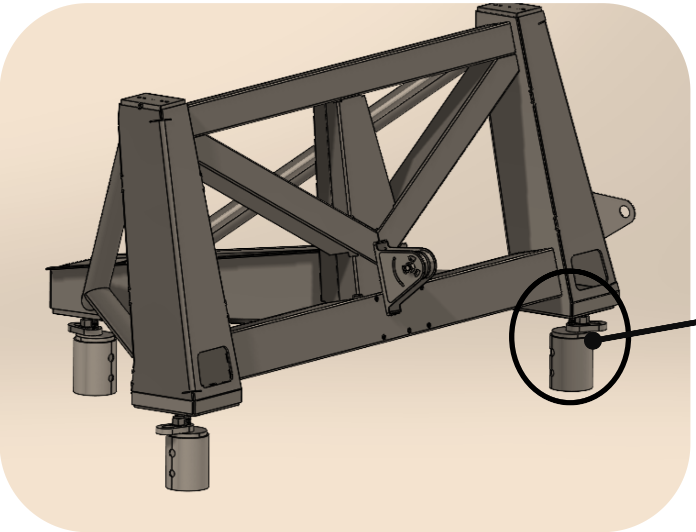


Elevation view looking at North

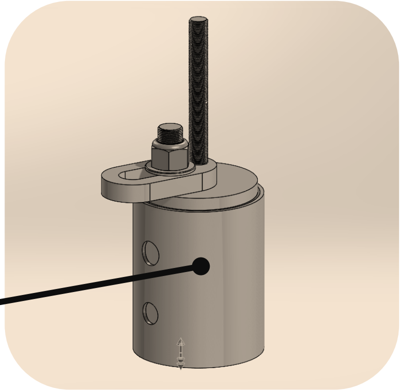


Foundation and pile caps

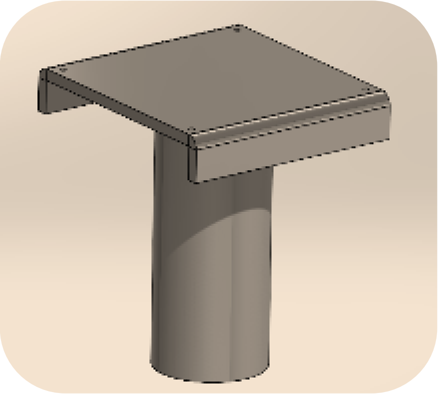
Alignment



Foundation to mount interface

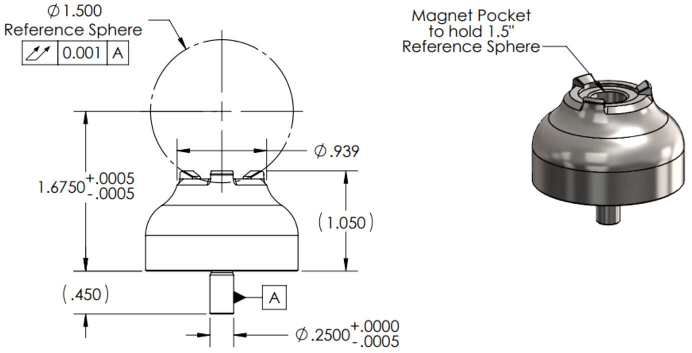


Foundation Pile cap



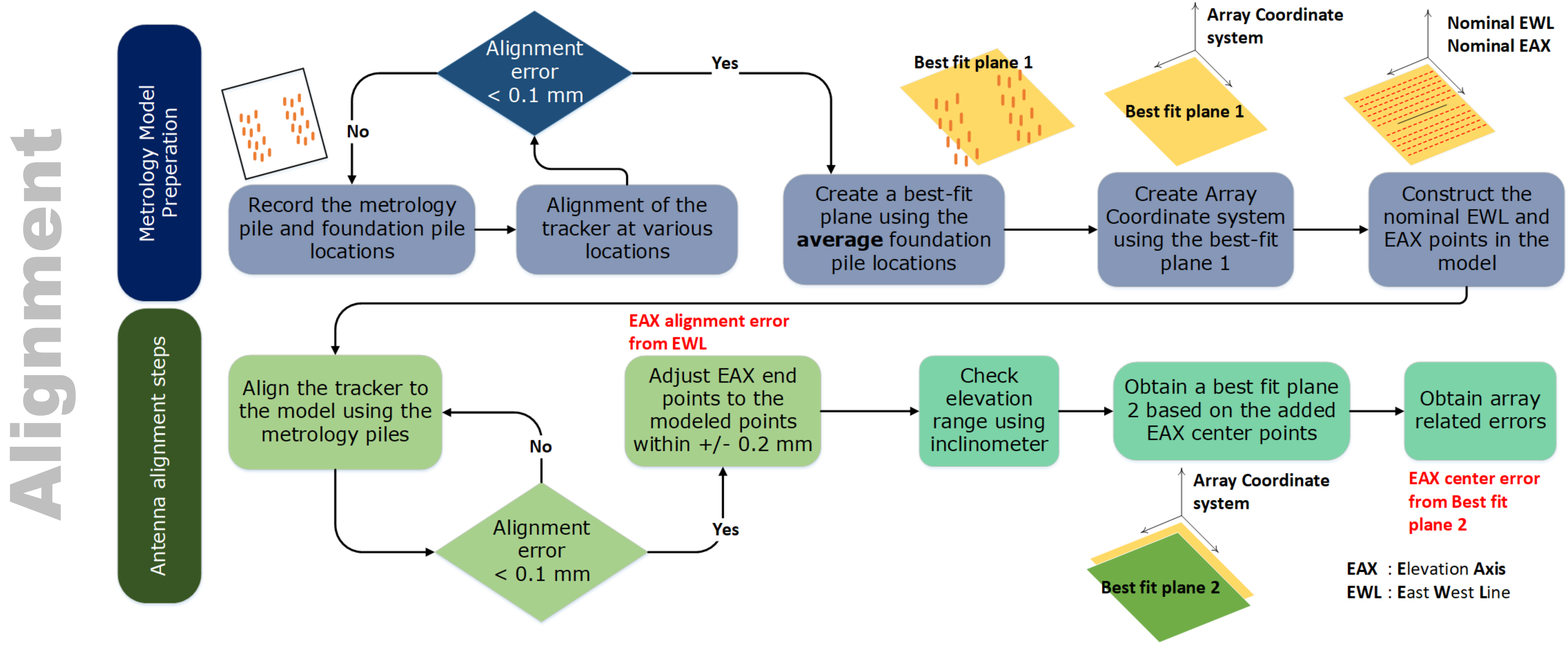
Metrology Pile cap with pin nest hole

Elevation axis point



Custom nest

Step by step antenna alignment strategy



NRC-CNRC

Possible challenges

Alignment

- Temperature variation and effect on the nominal points – seasonal variation
- Wind effect on the measurements can be critical, we have a consistent DRAO wind profile, we might have to pick a window to align antennas.
- Foundation movement during season change – this can be critical, we will monitor over the winter for the pathfinder array. Ground is fairly stable.
- Snow thawing will affect the ground for operations for a few weeks in the year

Summary

- Pathfinder array will be installed in October 2023
- Antenna verification using metrology has been discussed, Jigs will be used to align and assemble components. We have gained confidence from the CHORD prototype antennas
- Antenna alignment strategy and steps are presented. This is going to be challenging and interesting. We will test our equipment this fall once the pathfinder array is installed.
- Possible challenges in the alignment has been discussed

Q&A

Thank you