DISH STRUCTURE DETAIL DESIGN DOCUMENT

Document Number 316-000000-022
Revision 1
Author .... CETC54, MTM, SAM, ITC, SARAO
Date 2018-10-12
Document Classification .... CONFIDENTIAL
Status .... Release

Name	Designation	Affiliation	Signature & Date
Authored by:			
Du Biao	SKA-P Lead	CETC54	Du Biao Du Biao (Oct 12, 2018)
R. Aurigemma	Feed Indexer Lead	SAM	
Henk Niehaus	DS SE	SARAO	Henk Niehaus Henk Niehaus (Oct 10, 2018)
Approved by:			
Lutz Stenvers	Dish Structure Lead	MTM	Lutz Stenvers Lutz Stenvers (Oct 12, 2018)
Released by:			
Wang Feng	Dish Consortium Lead	CETC54	

DOCUMENT HISTORY

Revision	Date Of Issue	Engineering Change Number	Comments
A	2016-11-19	-	first release
1	2018-10-12	-	First release for pre-CDR submission representing the current design status

DOCUMENT SOFTWARE

	Package	Version	Filename
Word Processor	MS Word	Word 2013	316-000000-022_Dish_Structure_Detail_Design_Report_Rev1.doc
Block Diagrams			
Other			

ORGANISATION DETAILS

Name	**SKA Organisation**
Registered Address	Jodrell Bank Observatory Lower Withington Macclesfield Cheshire SK11 9DL United Kingdom Registered in England & Wales Company Number: 07881918
Fax	+44 (0)161 306 9600
Website	www.skatelescope.org

TABLE OF CONTENTS

Content

1 INTRODUCTION 17
1.1 Purpose of the Document 17
1.2 Scope of the Document 17
2 REFERENCES 18
2.1 Applicable Documents 18
2.2 Reference Documents 18
3 TECHNICAL SOLUTION 19
3.1 Illustration 20
3.2 Dish Structure Sub-Elements 24
3.2.1 General Description 24
3.2.1.1 Pedestal and Turnhead 24
3.2.1.2 Modular Design 25
3.2.2 Pedestal 26
3.2.2.1 Pedestal Tower Steel Structure 27
3.2.2.2 Pedestal Shielded Compartment 29
3.2.2.3 EMI Shielded Cabinet (EMISC) 33
3.2.2.4 Azimuth Actuators 36
3.2.2.5 Azimuth I/O Unit and Mount 39
3.2.3 Turnhead 46
3.2.3.1 Turnhead Steel Structure 47
3.2.3.2 Elevation Actuator 47
3.2.3.3 Elevation Encoder and Limit Switch Structure 51
3.2.4 Elevation Assembly 54
3.2.4.1 General 54
3.2.4.2 Main Reflector 55
3.2.4.3 Adjuster 61
3.2.4.4 BUS 63
3.2.4.5 Elevation Turnhead Frame 70
3.2.4.6 Subreflector 73
3.2.4.7 Support Arm 82
3.2.5 Indexer 85
3.2.5.1 Feed Indexer Main Components 85
3.2.5.2 Feed Indexer Main Platform and Payloads 86
3.2.5.3 Weight of the Indexer Assembly with Payloads 90
3.2.5.4 Bearings 92
3.2.5.5 Interface system 96
3.2.5.6 Platform Rotation mechanism 99
3.2.5.7 Bearings and Gears Maintenance – Lubrication 104

3.2.5.8 Indexer Actuators ... 112
3.2.5.9 Rotative Encoder ... 117
3.2.5.10 Dust & EMC Protection ... 124
3.2.5.11 Limit switches & Hard Stops ... 128
3.2.5.12 Feed Indexer Ray Tracing & keep out zones ... 131
3.2.5.13 Equipment for Testing and Assembly ... 131
3.2.5.14 Preliminary Packaging and Transportation Plan ... 135
3.2.5.15 Finite Element Analysis ... 139
3.2.5.16 Cable Routing ... 147
3.2.5.17 Design differences between SKA-P and SKA-MPI ... 159
3.2.6 Power Distribution ... 162
3.2.7 Ventilation System ... 167
3.2.8 Lightning Protection ... 171
3.2.8.1 Design Base line ... 171
3.2.8.2 Lightning damage analysis ... 171
3.2.8.3 Lightning Protection Zones ... 172
3.2.8.4 External Lightning Protection System ... 174
3.2.8.5 Down-conductor system ... 177
3.2.8.6 Internal lightning protection devices ... 181
3.2.9 Azimuth Cable Wrap ... 183
3.2.10 Elevation Cable Wrap ... 185
3.2.11 Cable Ducting ... 186
3.2.11.1 Foundation Cable Entry ... 186
3.2.11.2 Pedestal Inside Cable Routing ... 187
3.2.11.3 Turnhead cable routing ... 189
3.2.11.4 Elevation assembly cable routing ... 190
3.2.12 Helium System Mount ... 194
3.2.13 Access Ladders ... 195
3.2.14 Azimuth Bearing ... 198
3.2.15 Elevation Bearing ... 201
3.2.16 Azimuth Stow Lock ... 201
3.2.17 Brakes ... 202
3.2.18 Accessories ... 203
3.2.19 Control System NEW ... 204
3.2.19.1 Context ... 204
3.2.19.1 Block Diagram ... 206
3.2.19.2 Control Strategy ... 207
3.2.19.3 Safety System and Interlocks ... 208
3.2.19.4 Cable List ... 210
3.2.19.5 Drive Cabinet ... 211

4 PERFORMANCE STATEMENT ... 214

4.1 States & Modes ... 214
4.2 FE Model and Results ... 220
4.2.1 Description of the FE Analysis ... 220
4.2.1.1 FE Model ... 220

4.2.1.2 Material Properties 223
4.2.1.3 Considered Load Cases 223
4.2.2 FEA Results and Surface Accuracy 224
4.2.2.1 Deformations under the Gravity Load 224
4.2.2.2 Mode Analysis Results 227
4.2.2.3 Deformations under the Temperature Load 229
4.2.2.4 Surface Accuracy under Wind Loads 233
4.2.2.5 Total Surface Accuracy Analysis 240
4.2.2.6 Strength Analysis under the Gravity Load & Survival Wind Load (44.4m/s) 242
4.3 Performance Budgets 246
4.3.1 Radio Reflecting Efficiency 246
4.3.2 Reflector Phase Efficiency 246
4.3.3 Leakage through Reflector 247
4.3.3.1 Leakage through Main Reflector 247
4.3.3.2 Leakage through Subreflector 249
4.3.4 Maintain Pointing 250
4.3.4.1 Pointing Accuracy Performance 250
4.3.5 Uncompensated (Raw) Pointing Efficiency 253
4.3.5.1 Raw Pointing due to Wind Load Cases 253
4.3.5.2 Gravity 254
4.3.5.3 Raw Pointing due to Thermal Load Cases 254
4.3.6 Dynamic Analysis 254
4.3.6.1 Introduction 254
4.3.6.2 Model Overview 254
4.3.6.3 Controller 256
4.3.6.4 Transfer Functions 257
4.3.6.5 Dynamic Wind Analysis 263
4.3.6.6 Use Cases 270
4.4 EMI Shielded Compartment - Provide EMI Shielding 285
4.5 EMI Shielded Compartment - Provide Environment 287
4.6 Power Budget and Measuring of Consumption 290
4.7 Remote Support Capabilities 297
4.8 External Interfaces 297
5 SKA DISH STRUCTURE RFI DESIGN 298
5.1 General Description 298
5.1.1 SKA DS RFI Shielding Engineering Requirement 298
5.2 EMI/RFI shielding design of the PSC 299
5.2.1 Shielding Effectiveness Budget (PSC) 299
5.2.2 PSC enclosure 299
5.2.3 PSC door 300
5.2.4 PSC Power cable penetrations 300
5.2.5 PSC Servo Cables Penetrations 301
5.2.6 PSC Fibre Penetrations 302

5.2.7 PSC ventilation system 303
5.2.8 Lighting devices 304
5.3 EMI/RFI Shielding Design of the Equipment Inside the PSC 304
5.3.1 EMI Shielding Cabinet 304
5.3.2 EMI Shielding Servo Cabinet 305
5.4 EMI/RFI Shielding Design of the Equipment inside the Tower 311
5.4.1 Azimuth I/O unit 311
5.5 EMI/RFI shielding design of the equipment outside the tower/at the turnhead 312
5.5.1 Elevation I/O unit 312
5.5.2 Tilt meter 312
5.5.3 Indexer I/O unit 313
5.5.4 Warning horn and light 313
6 APPENDIX 315
6.1 Appendix: Sensitivity Analysis - Feed Indexer & Subreflector Deflections 315
6.1.1 Effects of the Feed Indexer Deflection on Dish Performance 316
6.1.2 Effects of the Subreflector Deflection on Dish Performance 319
6.2 Appendix: Pointing Error Budget 322
6.2.1 Contributors and Allocated Values 322
6.2.2 Adding of Errors 324
6.2.3 Load Cases 324
6.2.4 Detail Results 325
6.3 Appendix: Product Breakdown Structure 327
6.4 Appendix: SKA Dish PSC Ventilation Simulation 342
6.4.1 Theoretical Calculation 342
6.4.1.1 Heat loads 342
6.4.1.2 Vents 342
6.4.2 Computational Simulation 343
6.4.2.1 Model setup 343
6.4.2.2 Sunshield Cover 345
6.4.2.3 Cabinets 347
6.4.2.4 Vents 347
6.4.2.5 Airflow 349
6.4.3 Results 350

LIST OF FIGURES

Figure 1: SKA Dish Overview ... 19
Figure 2: 3D Model of the Dish... 20
Figure 3: Dish 2DDrawing, EL = 15° ... 21
Figure 4: Dish 2D Drawing, EL = 90° ... 21
Figure 5: Dish Active Area ... 22
Figure 6: Travel Relationship between two Dishes with a 30 m Distance ... 22
Figure 7: Two Dishes Operating at 15° Elevation Angle ... 23
Figure 8: Two Dishes Operating at 30 meters distance ... 23
Figure 9: Pedestal and Turnhead Assembly 3D Drawing ... 24
Figure 10: Main Dimensions of Pedestal and Turnhead ... 25
Figure 11: Pedestal Overview... 26
Figure 12: Overview of Lower Pedestal with Equipment ... 27
Figure 13: Overview of Middle Pedestal Section with Equipment... 28
Figure 14: Overview of Upper Pedestal Section with equipment ... 28
Figure 15: Pedestal Steel Structure ... 29
Figure 16: PSC Overview... 30
Figure 17: PSC Layout from Top ... 30
Figure 18: PSC Layout at Bottom... 31
Figure 19: PSC Layout around Fibre Penetration ... 31
Figure 20: EMISC Location inside the PSC ... 34
Figure 21. EMISC... 35
Figure 22. EMISC Power Distribution Unit ... 35
Figure 23: Azimuth Gearbox and Motor ... 36
Figure 24: Azimuth Actuator Cover and Airflow ... 37
Figure 25: Pre-Tension of Two Motors to Eliminate the Backlash ... 37
Figure 26: Azimuth I/O unit inside the Upper Pedestal Section... 39
Figure 27 Azimuth I/O Unit Lower End Mounting... 40
Figure 28: Azimuth I/O Unit Upper End Mounting... 41
Figure 29: Encoder and Limit Switches Electronics ... 42
Figure 30: Absolute Position Feedback Dr. Johannes Heindenhain, RCN8580 ... 43
Figure 31: Encoder Datasheet Page One... 44
Figure 32: Encoder Datasheet Page Two... 45
Figure 33: Overview of Turnhead Assembly (Front) ... 46
Figure 34: Overview of Turnhead Assembly (Rear)... 46
Figure 35: Turnhead Steel Structure ... 47
Figure 36: Elevation Actuator Overview... 47
Figure 37 Upper and Lower Mechanical Interface to Structure Overview ... 48
Figure 38: Elevation Axis Geometry ... 49
Figure 39: Elevation Transmission Ratio Total ... 49
Figure 40: Hollow Shaft Motor data... 50
Figure 41: Elevation I/O Unit Mounted on the Turnhead ... 51
Figure 42 Elevation I/O Unit Mounting ... 52
Figure 43: Elevation I/O Unit Shaft Transmission... 52
Figure 44: Elevation I/O Unit... 53
Figure 45: Geometry of Optics Design ... 54
Figure 46: Optical Path Geometry... 55
Figure 47: Geometry of Main Reflector Panels ... 56

Figure 48: Rib Layout by Topological Optimization ... 57
Figure 49: *left:* Triangle Distribution Ribs / *right:* Fishbone Distribution Ribs ... 57
Figure 50: Triangle Rib Layout and Deformation ... 58
Figure 51: Fishbone Rib Layout and Deformation ... 58
Figure 52: Optimization on Ribs ... 58
Figure 53: Final Panel Structure ... 59
Figure 54: Panel Fabrication ... 59
Figure 55: Single Panel Photograph ... 60
Figure 56: Single Panel Deformation under Gravity Load ... 61
Figure 57: Single Panel Thermal Deformation with Temperature Difference 50°C ... 62
Figure 58: Layout of Adjuster and Panel ... 62
Figure 59: Adjuster Distribution and Structure Diagram ... 63
Figure 60: Adjuster Structure Diagram ... 63
Figure 61: Single Tetrahedron Unit Diagram ... 64
Figure 62: Group Tetrahedron Unit Diagram ... 64
Figure 63: Backup Structure Diagram (1) ... 65
Figure 64: Backup Structure Diagram (2) ... 65
Figure 65: Backup Structure 2D Drawing ... 66
Figure 66: Diagrams of the Upper and Lower Chord Tubes (Ø76mm×3mm) ... 66
Figure 67: Diagram of the Interlayer Tube (Ø60mm×3mm) ... 66
Figure 68: Diagram of the Reinforced Chord Tube (Ø95mm×5mm, around the Reflector Support) ... 66
Figure 69: Diagrams of the Lower Tube Connected with the Reflector Support (Ø121mm×5mm) ... 66
Figure 70 Diagrams of the Tube Connected with the Counterweight (Ø121mm×5mm. Lengths of screw at both ends are different: the longer one is 137mm and the shorter one is 33mm which is same as the “green” tube in Figure 69.) ... 66
Figure 71: Exploded View of Bolt Connection ... 68
Figure 72: 2D Drawing of Bolt Connection ... 69
Figure 73: Chinese Standard of Bolted Knots ... 69
Figure 74: Elevation-Turnhead Frame Location Relationship Diagram ... 70
Figure 75: Elevation-Turnhead Frame 2D Drawing ... 71
Figure 76: Connection between the Elevation-Turnhead Frame and the Backup Structure ... 71
Figure 77: Connection between the Elevation-Turnhead Frame and the Turnhead and Ball Jackscrew ... 72
Figure 78: Elevation-Turnhead Frame Knots Structure Diagram ... 73
Figure 79: Subreflector Structure: Front and Back View ... 74
Figure 80: Subreflector Panels: Front View ... 75
Figure 81: Metal Spraying Robot ... 75
Figure 82 Sub-reflector panel model with three types of metal coating. ... 75
Figure 83: BUS of the Subreflector ... 76
Figure 84:Connection between carbon fiber tubes and ends ... 77
Figure 85: Layout Of Surface Precise Adjuster ... 77
Figure 86: Surface Precise Accuracy Adjuster ... 78
Figure 87: XY adjuster ... 79
Figure 88: Extension Structure ... 80
Figure 89: Connection between sub-reflector and its extension ... 81
Figure 90: Arm Structure Diagram ... 82
Figure 91 Feed indexer Stewart supporting structure ... 83
Figure 92 Detail structure of sub-reflector BUS Stewart ... 83
Figure 93 Four types of the hexapod-type tubes ... 84
Figure 94 Three types of the adjustable tubes in length ... 84
Figure 95 Feed Indexer View 1 ... 85

Figure 96 Feed Indexer view 2 85
Figure 97 Feed Indexer view from above 86
Figure 98 Feed Indexer bottom view 86
Figure 99 Feed Indexer Platform 87
Figure 100 Devices installed on top of the platform 88
Figure 101 Devices Keep Out Zones 89
Figure 102 SPF's Keep Out Zones 89
Figure 103 FI CoG 91
Figure 104 Bearing Installation 93
Figure 105 Interface with SPFs 97
Figure 106 Interface FI-Telescope Structure 98
Figure 107 Interface Flange 98
Figure 108 Interface with the telescope structure 99
Figure 109 Interface with the telescope structure: design details 99
Figure 110 Platform Rotation mechanism 100
Figure 111 Platform rotation 102
Figure 112 Driveline flexibility 103
Figure 113 Feed Indexer Bearings 108
Figure 114 Klüberplex BEM 41-141, product information 109
Figure 115 Klüberplex AG 11-461, product information 109
Figure 116 Feed Indexer Bearings lubrication 1 110
Figure 117 Feed Indexer Bearings lubrication 2 111
Figure 118 LENZE MCA14L20 113
Figure 119 Feed indexer encoder 117
Figure 120 Feed indexer encoder, Heidenhain EQN437 118
Figure 121 Encoder Data Sheet 119
Figure 122 Gears Design configuration 120
Figure 123 FI covers 125
Figure 124 FI IO Unit 126
Figure 125 EMI Flat Gasket 127
Figure 126 EMI-RFI spring installation 127
Figure 127 EMI-RFI Spring Seal 128
Figure 128 Limit switches 129
Figure 129 Hard stops position 129
Figure 130 Hard stops & Limit switches position 131
Figure 131 Dummy masses (SPF's) 132
Figure 132 Supporting Structure 133
Figure 133 FI factory tests facility 135
Figure 134: 20ft and 40ft HC ISO Container 136
Figure 135: 20ft and 40ft HC ISO container overall dimensions and weights 136
Figure 136: Feed Indexer 137
Figure 137: Feed Indexer custom pallet 137
Figure 138: Feed Indexer Prototype Transport in 20ft ISO HC Container 138
Figure 139: 16 Feed Indexer series transport in 40ft ISO HC Container 138
Figure 140: Handling of Feed Indexer into container by a 10T fork-lift truck 139
Figure 141: FE Model - Added mass 140
Figure 142: FE Model - Added mass 140
Figure 143: FE Model – Deformable Components 140
Figure 144: FE Model – Tapered roller bearings FE model 141
Figure 145: FE Model – Constrained Points 142
Figure 146: FE Results – Displacements and Rotations for the 9 used load conditions 142

Figure 147: FE Results – Displacements coordinate system used in the table in Fig. 53 143
Figure 148: FE Results – Total displacements field (Band 1 Feed – 90° Elevation) 143
Figure 149: FE Results – Von Mises stress field (Band 1 Feed – 90° Elevation) 144
Figure 150: FE Results – Total displacements field (Band 2 Feed – 90° Elevation) 144
Figure 151: FE Results – Von Mises stress field (Band 2 Feed – 90° Elevation) 145
Figure 152: FE Results – Total displacements field (Band 345 Feed – 90° Elevation) 145
Figure 153: FE Results – Von Mises stress field (Band 345 Feed – 90° Elevation) 146
Figure 154: Cable Routing 1 147
Figure 155: Cable Routing 2 149
Figure 156: Cable Routing 3 150
Figure 157: Cable Wrap 156
Figure 158 Igus Duct and cables/pipes positions, glass fibre rods positions 157
Figure 159 Igus Duct fixing connection points 158
Figure 160 SKA-P control box 159
Figure 161 SKA-MPI Cable Wrap bracket detail. 160
Figure 162 SKA-MPI safety connection access point 160
Figure 163 SKA-P covers. 161
Figure 164 SKA-MPI covers 161
Figure 165: The Context of Power Distribution 162
Figure 166: 3D Model and Position of Pedestal Power Distribution 163
Figure 167: Diagram of Pedestal Power Distribution 163
Figure 168: 3D Model and Position of PSC Power Distribution 164
Figure 169: Diagram of PSC Power Distribution 165
Figure 170: 3D Model and Position of Indexer Power Distribution 166
Figure 171: Diagram of Indexer Power Distribution 166
Figure 172: Ventilation window on the pedestal door 168
Figure 173 Turnhead Ventilation 168
Figure 174 PSC inlet and outlet ventilations 169
Figure 175: Sunshield around lower pedestal section 170
Figure 176: SKA1 MID DISH Lightning Protection Zones 173
Figure 177 Overview Diagram of the Down Conductor System 174
Figure 178 Air Termination Protection Range (Elevation angle=15°) 175
Figure 179 Air termination Protection Range (Elevation Angle=90°) 176
Figure 180 Sphere Check of Side Contact (Elevation Angle=15°) 176
Figure 181 Elevation Bearing Lightning Strap 179
Figure 182: Azimuth Bearing Lightning Slip Ring Brushes 180
Figure 183: Azimuth Cable Wrap Overview 183
Figure 184: Azimuth Cable Wrap Rotating Pattern 184
Figure 185 Elevation Cable wrap 185
Figure 186: Elevation cable wrap at EL=15° 185
Figure 187: Elevation cable wrap at EL=90° 185
Figure 188: The inner cable bending radius check of elevation cable wrap at EL=15° 186
Figure 189: Foundation Cables Entry 186
Figure 190: Cable Ducting in Lower Pedestal Section 187
Figure 191: Cable Ducting in Middle Pedestal Section 188
Figure 192: Cable Ducting in Upper Pedestal Section 188
Figure 193: Cable Routing Inside the Turnhead 190
Figure 194: Cable Routing Outside the Turnhead 190
Figure 195: Elevation Assembly Cable Tray Overview 191
Figure 196 Upper End of the Elevation Assembly Cable Tray 191
Figure 197: Cable tray with opened cover 192

Figure 198: Cable routing from Elevation Cable Wrap to Cable Tray 192
Figure 199: Cable Routing from Cable Tray to Feed Indexer Cable Wrap... 193
Figure 200: Model View of Helium Compressor Mount 194
Figure 201: Design for Maintenance of Helium Replenish Bottle 194
Figure 202: Outside Locking 195
Figure 203: Release Lock from Inside 195
Figure 204: Automatically Latched Open 196
Figure 205 Ladders in the lower pedestal section 197
Figure 206 Ladders in the middle and upper sections of pedestal 197
Figure 207 Turnhead hatch 198
Figure 208: Azimuth Ball Bearing Overview 198
Figure 209: Azimuth Ball Bearing Specification.. 199
Figure 210: Azimuth Ball Bearing Static Limiting Load Curves 200
Figure 211: Operation Load Service Life 200
Figure 212: Elevation Bearing and Bracket 201
Figure 213: Distribution of Azimuth Stow Holes 202
Figure 214: Azimuth Stow Motor and Locking Assembly.. 202
Figure 215: Control System Context.. 205
Figure 216: Block Diagram of the Dish Motion Control System Based on MTM Toolbox 206
Figure 217: Software, Real Time and Normal Operating System.. 207
Figure 218: Beckhoff Safety Terminals... 208
Figure 219: Drive Cabinet 211
Figure 220: Drive Cabinet Details and Internal Layout... 212
Figure 221 Drive Cabinet inside PSC.. 213
Figure 222 States and Modes for the General Telescope Status 214
Figure 223 Azimuth and Elevation to General Status transition table 214
Figure 224: Signed Remote ICD for Dish Structure Controller to LMC... 216
Figure 225 Software modules of the MTM7 SKA Dish Controller 217
Figure 226: Maintenance GUI Example.. 217
Figure 227: Handheld Device 218
Figure 228: Local Lockout-Tag-Out Box incl. Emergency Stop and HHD Connection Point 219
Figure 229 FE Models for the reflector at typical elevation positions 221
Figure 230 Detailed View of the FE Model for Several Local Structures... 221
Figure 231 Constrained boundary 222
Figure 232 Deformation under the Gravity Load (Unit: mm).. 224
Figure 233 Surface Accuracy of the Main Reflector under Gravity Load 225
Figure 234 Surface Accuracy of the Subreflector under Gravity Load 225
Figure 235 Total Surface Accuracy under Gravity Load 225
Figure 236 Model in the GRASP with the consideration of the deformation under the gravity load 226
Figure 237 Direction of the Elevation Gain (@EI=15°, 20GHz)... 226
Figure 238 Direction of the Elevation Gain (@EI=90°, 20GHz)... 227
Figure 239 Aperture Efficiency Calculated by the Ruze Formula and GRASP (@20GHz).................... 227
Figure 240 First Mode Results of the Antenna at Different Elevation Positions................................. 228
Figure 241 First 6 Modes of the Antenna @ El=15° 229
Figure 242 Gradient Temperature Fields in Standard and Degraded Operating Conditions............. 230
Figure 243 Temperature Distribution of the Standard Condition and the Corresponding Deformation @ El=15° 230
Figure 244 Temperature Distribution of the Standard Condition and the Corresponding Deformation @ El=45° 231
Figure 245 Temperature Distribution of the Standard Condition and the Corresponding Deformation @ El=90° 231

Figure 246 Errors of the Main Reflector and Subreflector under the Standard Temperature Condition 232
Figure 247 Maximum errors of the Antenna under the Standard Temperature Condition 232
Figure 248 Errors of the Main Reflector and Subreflector under the Degraded Temperature Condition 233
Figure 249 Maximum errors of the Antenna under the Degraded Temperature Condition 233
Figure 250 Wind Pressure Distributions on the Antenna at Different Elevations and 0° Azimuth Angle (Unit: Pascal) 236
Figure 251 Wind Pressure Distributions on the Antenna at Different Azimuths and 30°Elevation Angle (Unit: Pascal) 238
Figure 252 Surface Accuracy at 5m/s Wind Load 238
Figure 253 Surface Accuracy at 7m/s Wind Load 239
Figure 254 Surface Accuracy at 10m/s Wind Load 239
Figure 255 Surface Accuracy in Precision Operating Condition 240
Figure 256 Surface Accuracy in Standard Operating Condition 240
Figure 257 Surface Accuracy in Degraded Operating Condition 241
Figure 258 Reflector Phase Efficiency in the Three Operating Conditions (Ruze Formula) 241
Figure 259 Fluid Path Lines around the Antenna under the Survival Wind Load 242
Figure 260 Pressure Contour Map of the Antenna under the Survival Wind Load (Unit: Pascal) 242
Figure 261 Reflector Pressure Contour Map under the Survival Wind Load (Unit: Pascal) 243
Figure 262 Subreflector Pressure Contour Map under the Survival Wind Load (Unit: Pascal) 243
Figure 263 Pedestal Pressure Contour Map under the Survival Wind Load (Unit: Pascal) 243
Figure 264 Stress Contour Maps on the Yoke and the Pedestal under the Gravity and Survival Wind Load 244
Figure 265 Stress Contour Map on the BUS (Maximum=386MPa) 244
Figure 266 Detailed FE Model for the Knot Structure and the Final Stress Contour Map (Maximum=325MPa) 245
Figure 267: Dish Model Built in FEKO 247
Figure 268: The radiation pattern comparisons between main reflector with and without gaps 248
Figure 269: Energy Ratio of the Side Lobes Behind the Main Reflector 248
Figure 270 Sub-reflector panel model with three types of metal coating. 249
Figure 271: Ratio of the scattering energy behind the sub-reflector to full energy 249
Figure 272: Two Example Positions of the Mount Structure Used for Simulation 255
Figure 273: Architecture of the Axis Controller 256
Figure 274: Open Velocity Loop Frequency Responses for Azimuth 258
Figure 275: Closed Velocity Loop Frequency Responses for Azimuth 258
Figure 276: Open Position Loop Frequency Responses for Azimuth 259
Figure 277: Closed Position Loop Frequency Responses for Azimuth 259
Figure 278: Open Velocity Loop Frequency Responses for Elevation 261
Figure 279: Closed Velocity Loop Frequency Responses for Elevation 261
Figure 280: Open Position Loop Frequency Responses for Elevation 262
Figure 281: Closed Position Loop Frequency Responses for the Elevation Axis 262
Figure 282: Main Steps of the Dynamic Wind Analysis 264
Figure 283: Normalised Wind Spectra for 3 Categories: Empirical vs. Measured 265
Figure 284: PSD of the Close Loop Disturbance System Response for Azimuth (AZ) and Pointing Cross-Elevation (XEL) Axes 269
Figure 285: PSD of the Close Loop System Response for Elevation (EL) and Pointing Elevation (PEL) Axes 269
Figure 286: EMISC Shielding Effectiveness test setup 285
Figure 287: EMISC Shielding Effectiveness test results – Vertical Polarization 286
Figure 288: EMISC Shielding Effectiveness test results – Horizontal Polarization 286

Figure 289: EMISC Stack-Up for Thermal Analysis 288
Figure 290: EMISC Thermal Analysis Results 289
Figure 291: Power Converter 295
Figure 292: EL3403 Power Measuring Terminal 295
Figure 293: Technical Data of EL3403 296
Figure 294: TwinCAT Scope View 297
Figure 295: Delivered RFI Shielded Door 300
Figure 296: The Power EMI Filters on PSC Inner Wall 301
Figure 297: EMI shielding for Servo Cables Inside PSC 302
Figure 298: Ventilation EMI design 303
Figure 299: Shows the EMISC as tested in the anechoic chamber 304
Figure 300 Drive Cabinet: 305
Figure 301: shows the type of braiding between the DC Filters and the PSC roof feed rough plate . 306
Figure 302: Showing transmission curve and derating curve of a Bajog filter 310
Figure 303: Showing the Azimuth IO-Unit with EMI Filter mounted and the sealed shaft 311
Figure 304: Showing the Elevation IO-Unit with EMI Filter and waveguide penetrations as well as 312
Figure 305: Showing the tilt meter 312
Figure 306: Shows the Feed Indexer as well as the filter and the waveguide fibre penetration 313
Figure 307: Warning horn (top) and warning light (bottom) 314
Figure 308: Coordinate of the Dish 315
Figure 309: Simulation Model in GRASP 315
Figure 310: Pressure Diagram of the Fans 343
Figure 311: Geometry Model of the Pedestal 344
Figure 312: Vent Grille Setup 344
Figure 313: Solar Load Model Parameters 345
Figure 314: Temperature Distribution on the Outer Surface of the Pedestal 346
Figure 315: Temperature Distribution on Horizontal Section of the Pedestal 346
Figure 316: Temperature surrounding the cabinets 347
Figure 317: Temperature Distribution on the Vents of the Pedestal 348
Figure 318: Airflow Speed on the Vents 348
Figure 319: Airflow Speed on the Pedestal Door Vents 349
Figure 320: Airflow in Pedestal 349

LIST OF TABLES

Table 1: List of equipment located inside the EMISC 33
Table 2 Azimuth Torque Budget 38
Table 3: Dish Geometry Parameters 54
Table 4: Area of the Half Panels for the Main Reflector 56
Table 5 Knots Structure Diagram 67
Table 6 Feed Indexer Platform elements 87
Table 7 Payloads installed on the platform 87
Table 8 Feed Indexer components and total weight 90
Table 9 Bearing characteristics 92
Table 10 Bearing design data 93
Table 11 Geometric parameters of the system 100
Table 12 Driveline flexibility design data 103
Table 13 Greases Characteristics 106
Table 14 Feed Indexer bearings maintenance characteristics 107
Table 15 Actuator sizing design data 112
Table 16 Motor characteristics 114
Table 17 Indexer torque budget 116
Table 18 Motor Gears design data 120
Table 19 Encoder Gear design data 122
Table 20 Gears Fatigue analysis 123
Table 21 Hard Stops design 130
Table 22 Dummy masses 132
Table 23 Cable routing (Cables/Pipes list) 151
Table 24 Cable Wrap (Cables/Pipes list) 155
Table 25: Main Parts of Pedestal Power Distribution 164
Table 26: Main Parts of PSC Distribution 165
Table 27: Main Parts of Indexer Power Distribution 166
Table 28: Cable list of Power Distribution 167
Table 29 Maximum current levels (relating to sizing efficiency) for LPL I to IV and probability of exceeding these levels. 171
Table 30 Minimum current levels (related to interception efficiency) for LPL I to IV 172
Table 31 Class of LPS and Lightning Protection Level (LPL) 172
Table 32: Lightning Protection Zone Definition 172
Table 33: Dish Control System main sub-systems 204
Table 34: Servo System Cable List 210
Table 35 Material Properties used in FEA 223
Table 36 Weight Distribution in the Model 223
Table 37 First Order Resonant Frequencies of the Antenna at Different Elevation Angle 228
Table 38 First 6 Resonant Frequencies of the Antenna at El=15° 229
Table 39 Load Cases to calculate the Surface Accuracy 240
Table 40: Reflector Phase Efficiency over Frequency and Elevation Angle 247
Table 41: Predicted Pointing Performance - Precision Operating Conditions 250
Table 42: Predicted Pointing Performance - Standard Operating Conditions 251
Table 43: Predicted Pointing Performance - Degraded Operating Conditions 252
Table 44: Scaling Based on Wind Speed 252
Table 45: Pointing Accuracy due to wind @ 2.7m/s 253
Table 46: Pointing Accuracy due to Thermal Load Cases 254

Table 47: Maximum Velocity and Acceleration 254
Table 48: Control Loop Performance for the Azimuth Axis 259
Table 49: Control Loop Performance for the Elevation Axis 262
Table 50: Wind speed characteristics for different categories 263
Table 51: Parameters for the Wind Speed Spectra 264
Table 52: Dynamic Wind Results for the Precision Conditions 266
Table 53: Dynamic Wind Results for the Standard Conditions 267
Table 54: Dynamic Wind Results for the Degraded Conditions 268
Table 55: DS Power Budget Table 295
Table 56: Dish Performance at the Feed Displacement along X_f Axis 316
Table 57: Dish Performance at the Feed Displacement along Y_f Axis 316
Table 58: Dish Performance at the Feed Displacement along Z_f Axis 316
Table 59: Dish Performance at the Feed Rotation in ϑ_f 317
Table 60: Dish Performance at the Feed Rotation in Φ_f 317
Table 61: Dish Performance at the Feed Displacement at Worst Cases 317
Table 62: Dish Performance with the Feed Displaced along X_s Axis 319
Table 63: Dish Performance with the Feed Displaced along Y_s Axis 319
Table 64: Dish Performance with the Feed Displaced along Z_s Axis 319
Table 65: Dish Performance at the Feed Rotation in ϑ_s 320
Table 66: Dish Performance at the Feed Rotation in Φ_s 321
Table 67: Dish Performance at the Feed Rotation in Ψ_s 321
Table 68: Dish Performance at the Subreflector Displacement at Worst Cases 321
Table 69: Pointing Error Budget Contributors 323
Table 70: Adding of the Errors 324
Table 71: Example of Detail Pointing Budget Sheet 325
Table 72: Illustration of the Steady State Wind Error and Effect of a Tilt Sensor 326

LIST OF ABBREVIATIONS

SKA................................ Square Kilometre Array

SKAO .... SKA Project Office

1 Introduction

1.1 Purpose of the Document

This document serves as the design report for the detail design review of the SKA1-MID-dish structure element and describes the current status and results of the joined design activities of CETC54, MT Mechatronics, SAM and StratoSat.

1.2 Scope of the Document

The document covers the technical solution of the Dish Structure, the detail design of dish structure sub element, performance statement, FEA results and performance analysis.

2 References

2.1 Applicable Documents

The following documents are applicable to the extent stated herein. In the event of conflict between the contents of the applicable documents and this document, **the applicable documents** shall take precedence.

[AD1] SKA-TEL-DISH-0000041 SKA1 DISH ELEMENTS POWER MANAGEMENT,REV01

[AD2] 301-000000-018 DEVELOPER GUIDELINES TO SANA 10142-1 & SAN60950-1 FOR DSH ELECTRICAL SAFETY

2.2 Reference Documents

The following documents are referenced in this document. In the event of conflict between the contents of the referenced documents and this document, **this document** shall take precedence.

[RD1] SKA-TEL-DSH-0000011, Rev5-- DISH STRUCTURES (DS) REQUIREMENTS SPECIFICATION

[RD2] 316-060000-001 SKA Servo System Layout Diagram 20161108.pdf

[RD3] 316-060000-001 SKA Servo System Junction Box 20161108.pdf

[RD4] 316-060000-001 SKA Cable_List_20161110.pdf

[RD5] 316-060000-002 Drive System Requirement Specification -- RevA -- 2016-11-11

[RD6] 316-060000-005, Elevation Actuator Requirement Specification -- RevA -- 2016-11-11

[RD7] 316-040000-001, Feed Indexer Requirement Specification – RevA – 2016-11-13

3 Technical Solution

The proposed dish for SKA is a 15.0-meter multi panel dual shaped offset Gregorian antenna in accordance with the specified antenna optics. The antenna reflector is configured with the feed arm, feed indexer and passive sub reflector below the main reflector (feed down concept).
The pedestal incorporates a tower-mounted turning head steel structure to develop an elevation-over-azimuth positioning system. Several feeds provided by SKA will be integrated into the feed indexer. The feed indexer allows precision positioning of a single feed at the secondary focus of the ellipsoidal subreflector.
In azimuth, the antenna pedestal is equipped with two electrically torque-biased gearbox drive units and in elevation with a precise low backlash ball screw jack driven by a torque motor and brake. This design in combination with the antenna control system yields a high precision telescope system with excellent accuracy pointing. The entire dish design is shown Figure 1 and Figure 2.

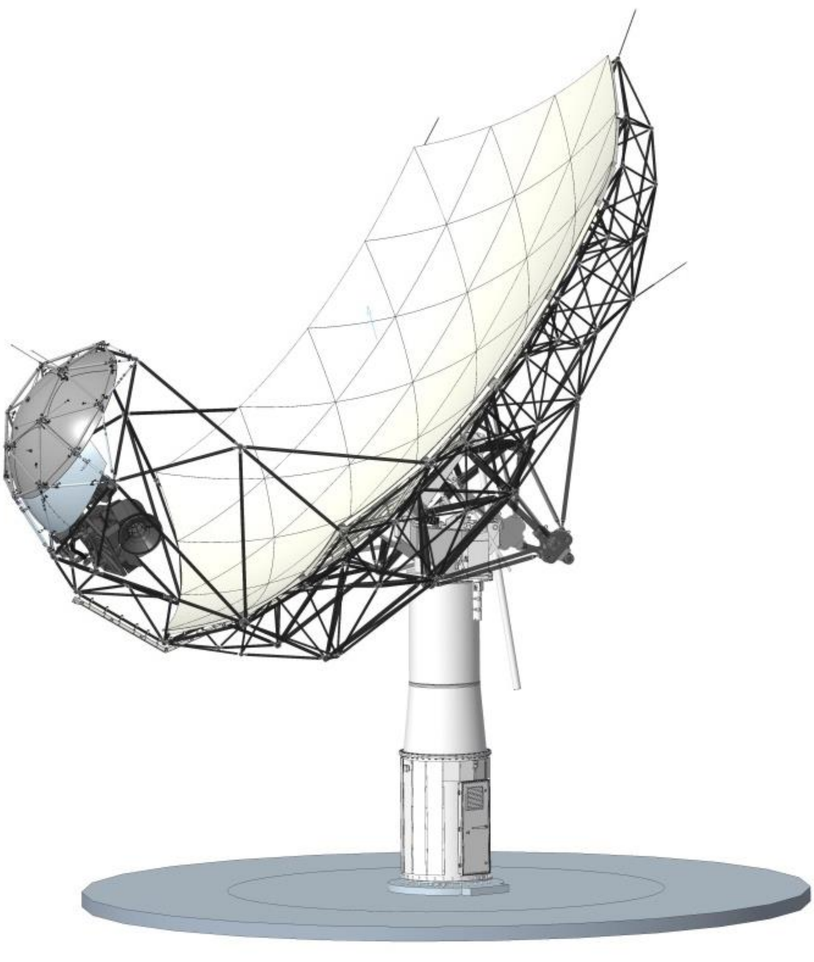


Figure 1: SKA Dish Overview

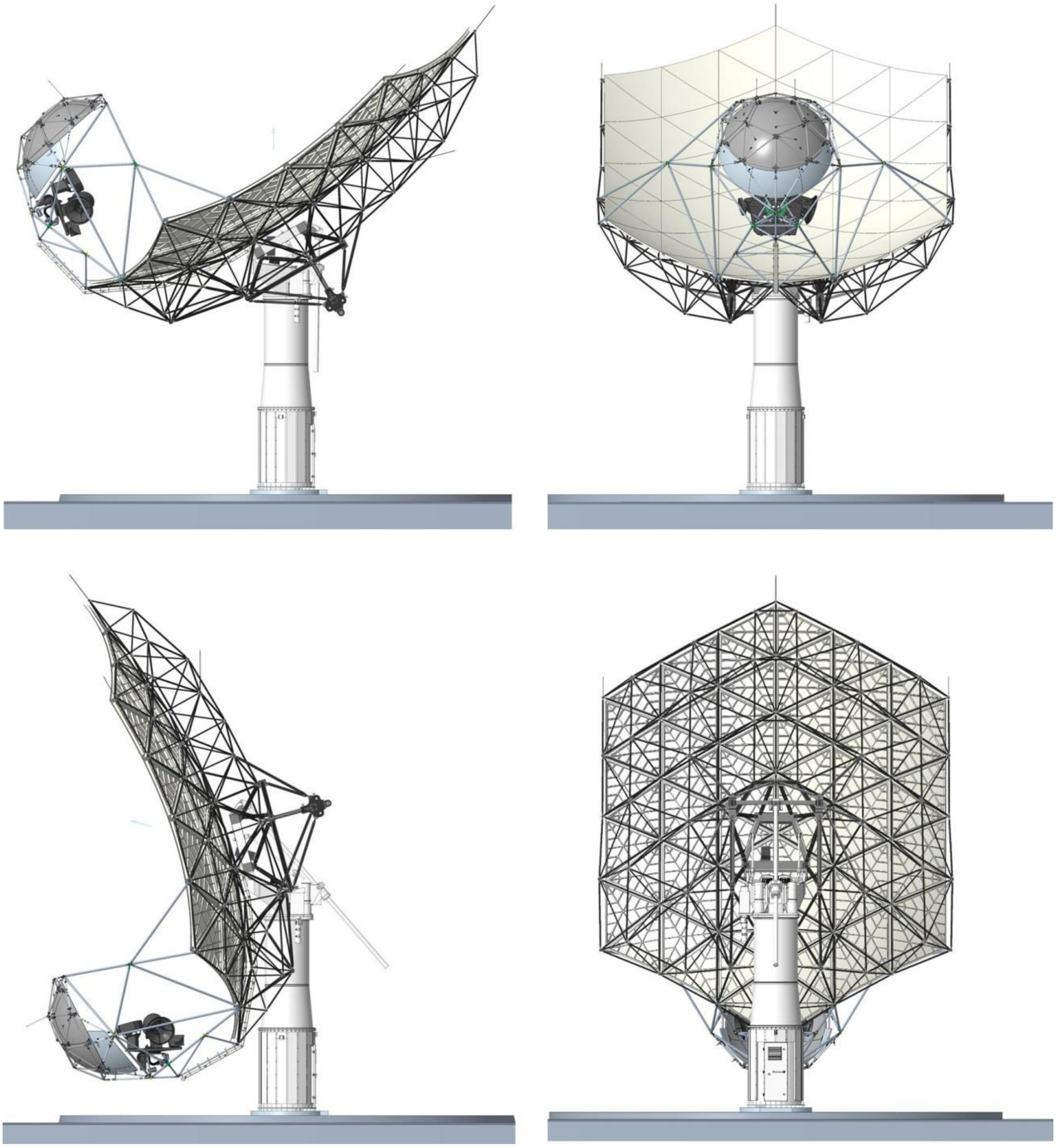


Figure 2: 3D Model of the Dish

3.1 Illustration

The dish structure is composed of elevation assembly, indexer, pedestal, turnhead, and control system. The elevation assembly adopts the Panelled Space frame-supported technical solution with metal panels for the main-reflector and CFRP panels for the sub-reflector.

The dish structure design has sufficient stiffness to ensure that the phase centre of dish shall remain within a radius of 100 µm from the ideal position under the precision and standard operating conditions, over 1000 second periods and 15° pointing change in either axis.

The 2D drawings of the dish are shown in Figure 3 and Figure 4.

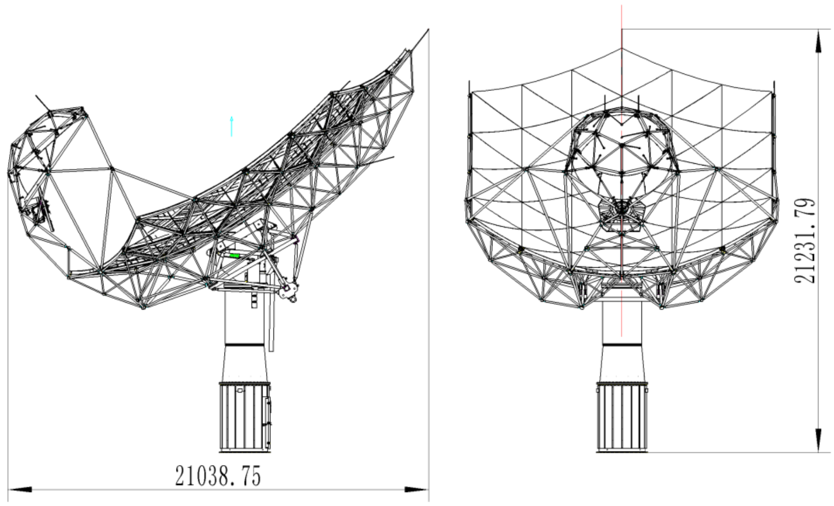


Figure 3: Dish 2DDrawing, EL = 15°

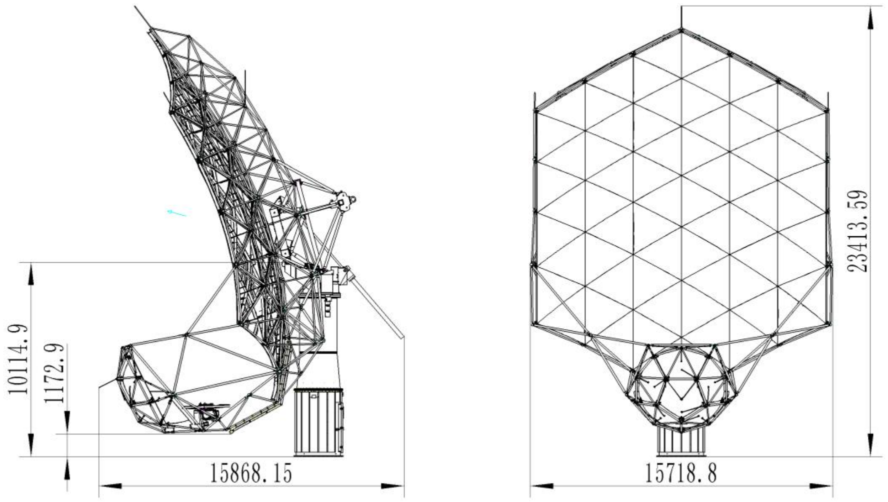


Figure 4: Dish 2D Drawing, EL = 90°

The EL operational travel range of the dish is shown in Figure 5.

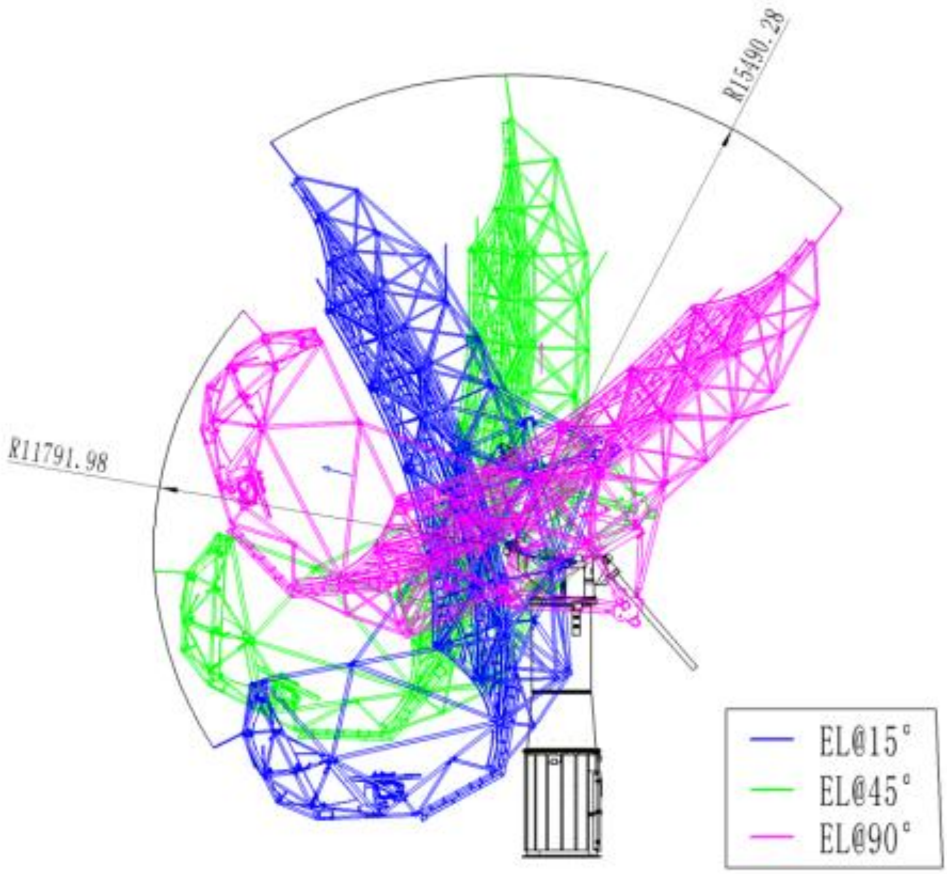


Figure 5: Dish Active Area

The relationship between two dishes and their travel range located with a centre-to-centre spacing of 30 meters are given in Figure 6, which shows no possibility of collision between the two dishes.

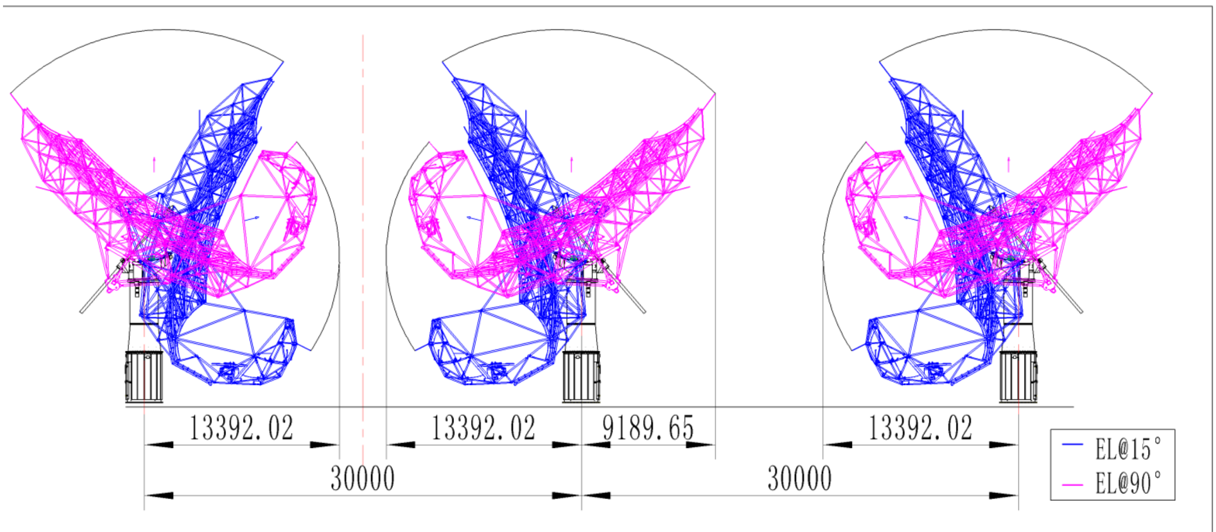


Figure 6: Travel Relationship between two Dishes with a 30 m Distance

When the dish array observes at 15° elevation angle, the minimum distance between two dishes without blockage is 67.1 meters, as shown in Figure 7. When the distance of two dishes is 30 meters, the minimum observation angle is 35.5°, as shown in Figure 8.

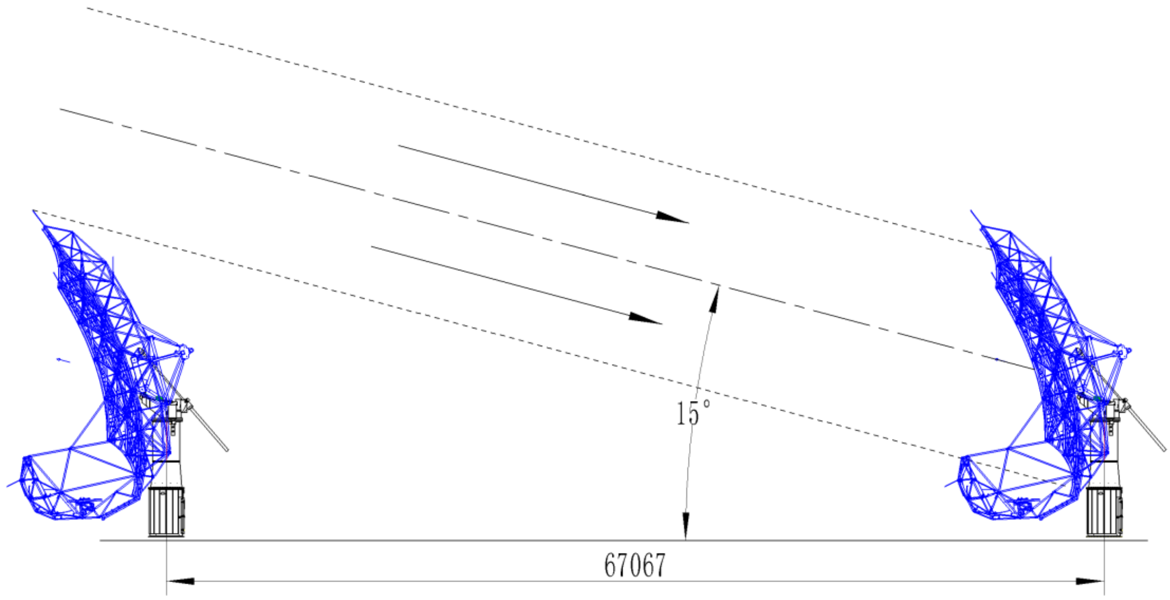


Figure 7: Two Dishes Operating at 15° Elevation Angle

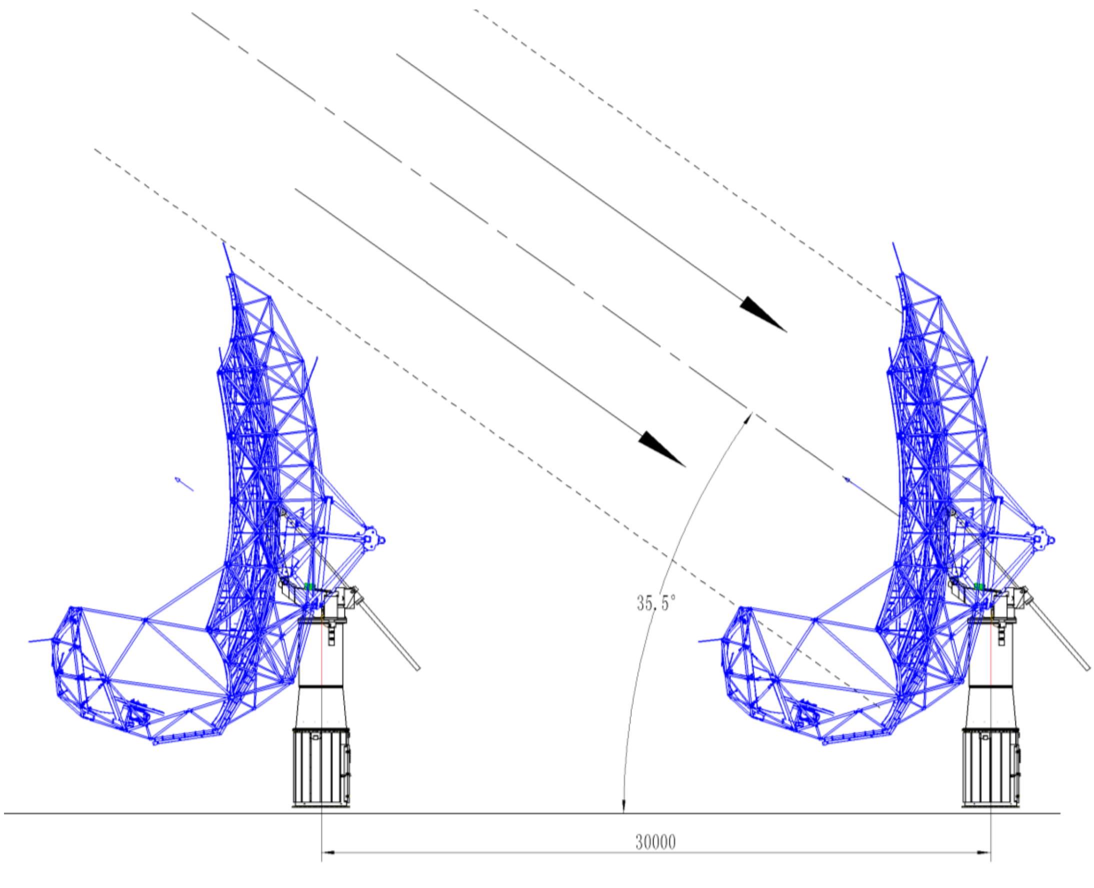


Figure 8: Two Dishes Operating at 30 meters distance

3.2 Dish Structure Sub-Elements

This section illustrates and describes the layout, detail solution, materials used & fabrication methods of dish structure sub-elements.

3.2.1 General Description

3.2.1.1 Pedestal and Turnhead

The key function of pedestal and turnhead assembly is to provide sufficiently stiff rotatable azimuth and elevation axis, an accurate and stiff base for feed indexer and an enclosed space for various systems and ancillary equipment, protecting the inside equipment and outside radio frequency environment. Figure 9 and Figure 10 show the overview and the interface dimension of the pedestal and turnhead. The elevation over azimuth mount type is adopted.

The pedestal assembly has a continuous useable azimuth observation range from -270° to +270° inclusive, measured relative to true North defined as 0° and with East defined as +90°.The elevation travel range is from 15° through to 90° inclusive, measured relative to the local horizon defined as 0° and with a Zenith defined as +90°.

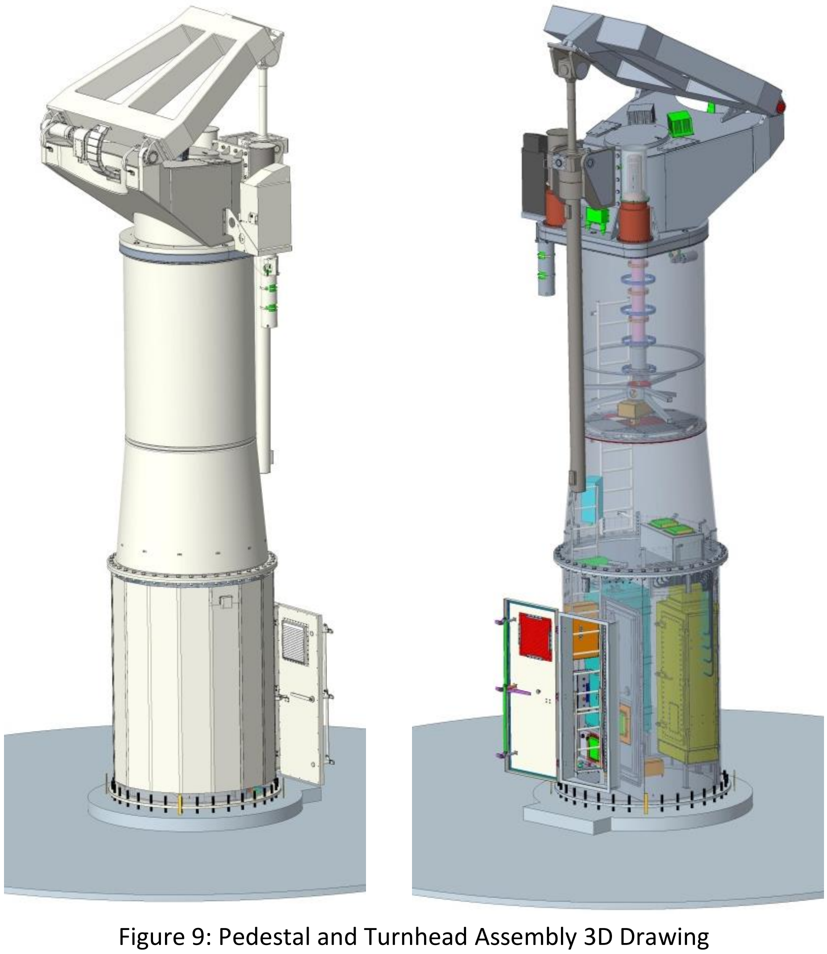


Figure 9: Pedestal and Turnhead Assembly 3D Drawing

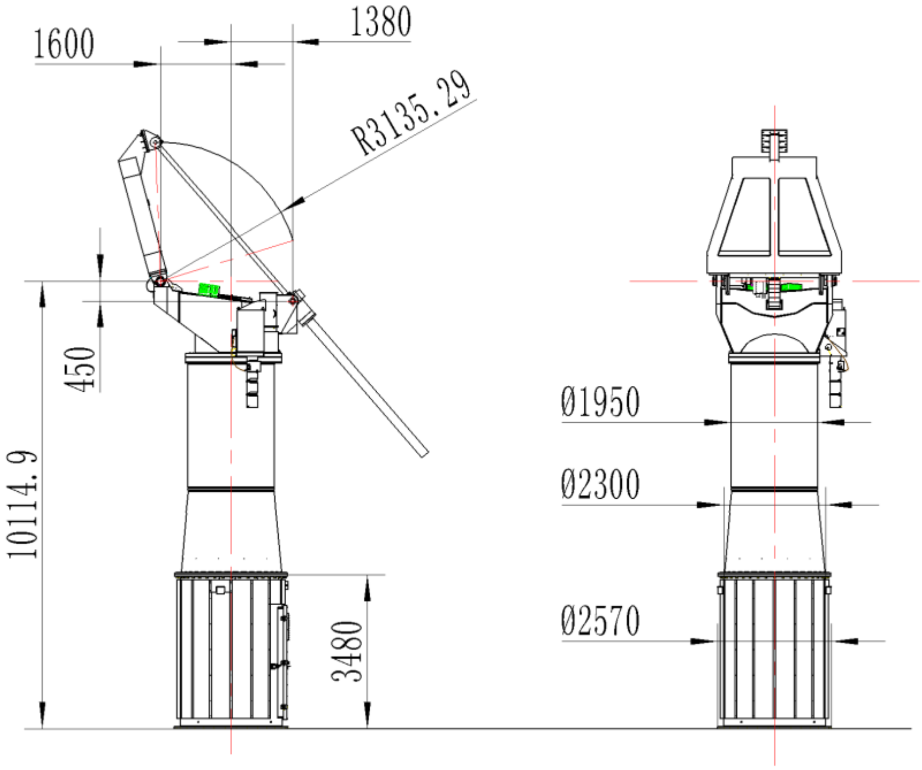


Figure 10: Main Dimensions of Pedestal and Turnhead

3.2.1.2 Modular Design

The pedestal tower steel structure, turnhead steel structure, azimuth bearing, elevation bearings are designed as modules that are easy for transportation and integration. The actuators, motors, gearboxes and entry door, etc., are designed as line replaceable unit (LRU) that are easy for replacement on site, where the required working hours are less than 12 hours.

The design ensures that the LRUs are interchangeable and share the same part number. No calibration, turning and alignment is expected for on-site maintenance and replacement. Also, the calibration, tuning, aligning or other actions for depot maintenance are minimized.

To achieve the fast integration especially for the LRU, the size, type and number of fasteners are minimized without any compromise to security and safety requirements. The mounting interfaces of module are designed to be preclusive from the wrong assembly, for example the key coding connector. The module is equipped with mounting guides and locating pins for easy integration especially for the LRU.

In addition, the special equipment for holding the elevation assembly, indexer and turnhead are designed and are provided for the line replaceable unit maintenance.

The handles are designed for components to be installed on site and the replaceable units ranging from 15 kg to 40 kg. The components to be installed on site and the replaceable units heavier than 40kg are equipped with lifting point or holes for eyebolts.

3.2.2 Pedestal

The pedestal tower consists of pedestal steel structure, pedestal shielded compartment, doors, platforms and ladders. The pedestal tower integrated with azimuth bearing, azimuth cable wrap, azimuth I/O unit assembly, cabinets and power distribution system, as shown Figure 11.

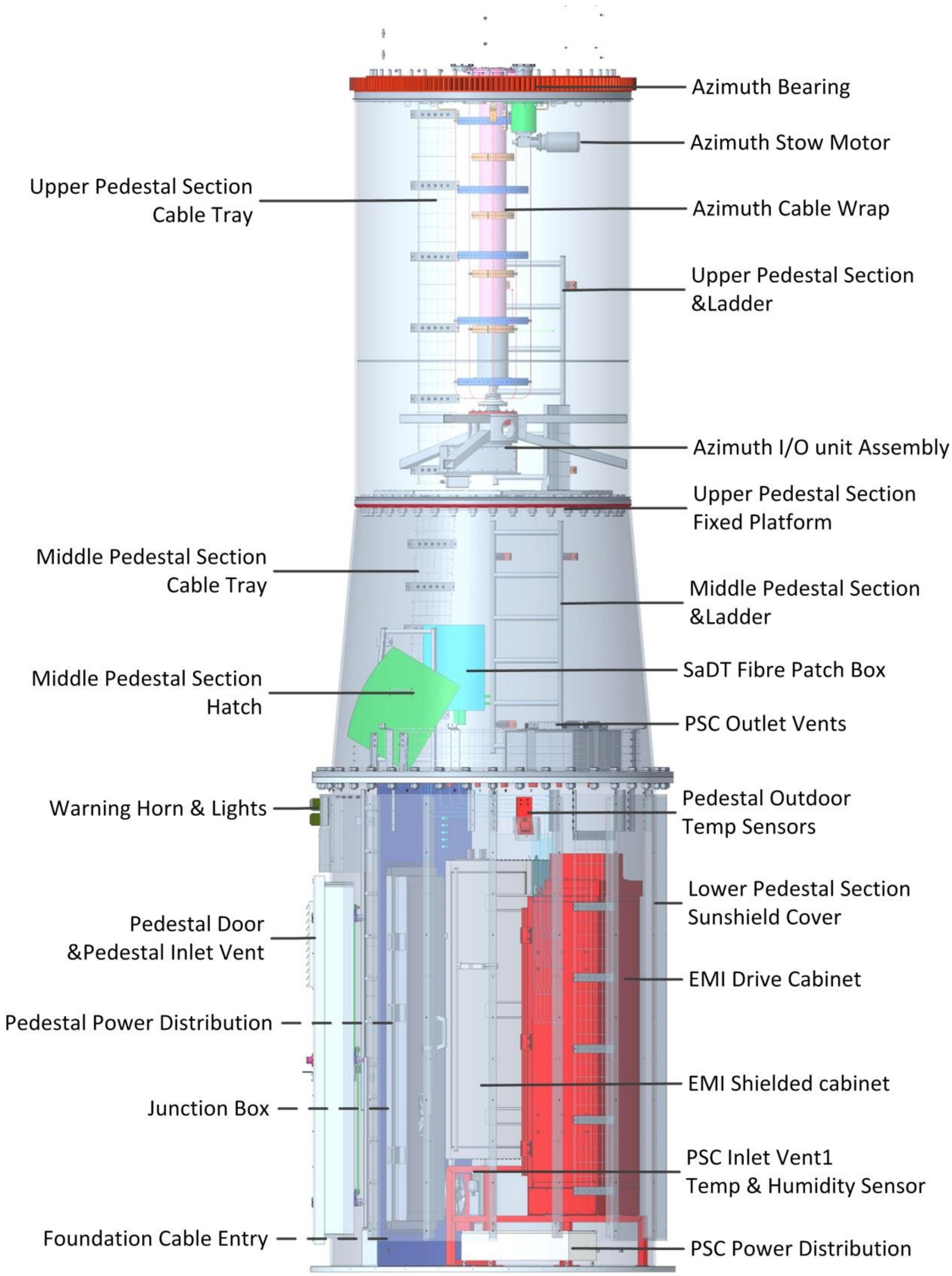


Figure 11: Pedestal Overview

3.2.2.1 Pedestal Tower Steel Structure

The pedestal tower steel structure consists of three modules with the welded steel plate structure as described as bellow.

1) **Lower Pedestal Section**

The lower pedestal section is fixed to the foundation by screws. It is integrated with pedestal entry door, ladder, power distribution and pedestal shielded compartment, servo cabinet and EMISC etc, as shown in Figure 12.

The lower section is divided by a stainless steel wall with an EMI door, forming up an individual EMI shielded compartment (PSC) where all equipment with risk to produce EM interference are located. The other part of the section provides the ladders and cable tray to the middle section, the cable entry from the foundation, power distribution and servo junction box.

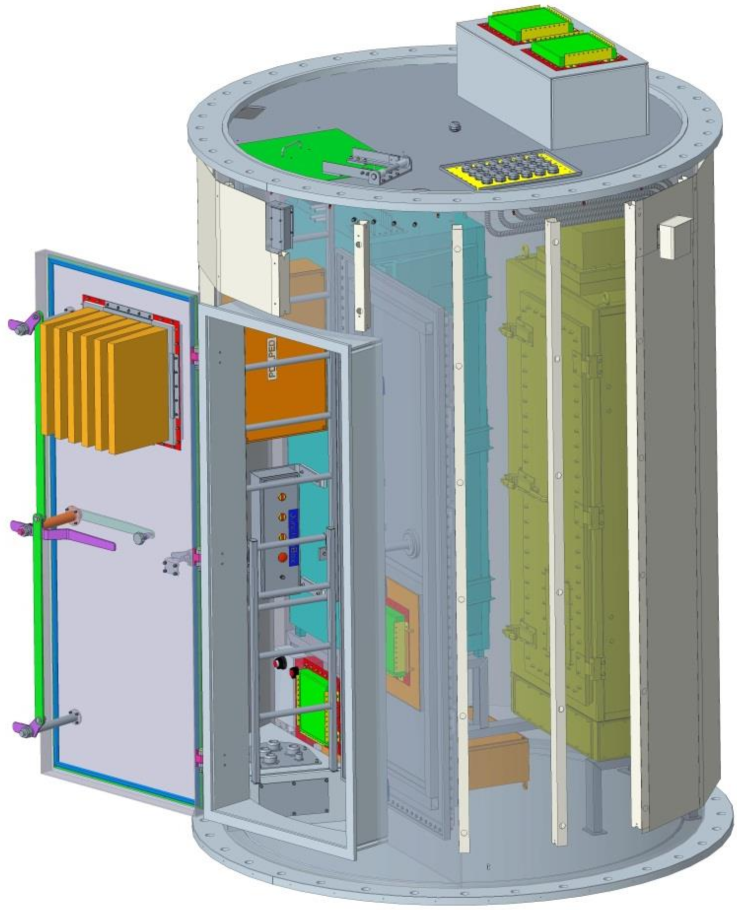


Figure 12: Overview of Lower Pedestal with Equipment

2) Middle Pedestal Section

The middle pedestal section is a conical welded steel part that connects the lower and upper section of pedestal. It is integrated with ladders, SaDT fibre routing box as well as the PAF fibre routing box in the future. It provides the access between the lower and upper section of pedestal for personnel, cables and fibres as shown in the Figure 13.

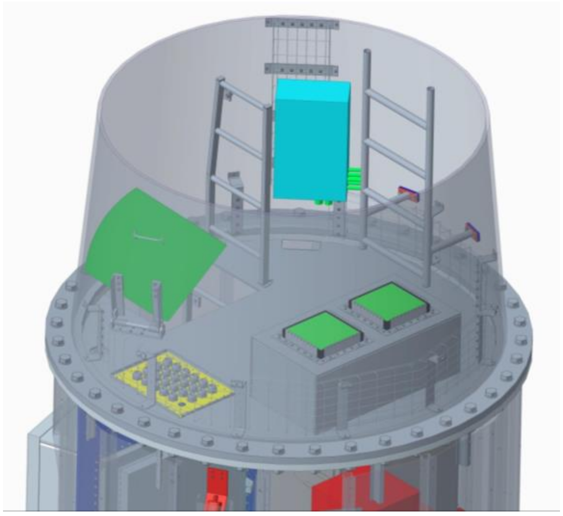
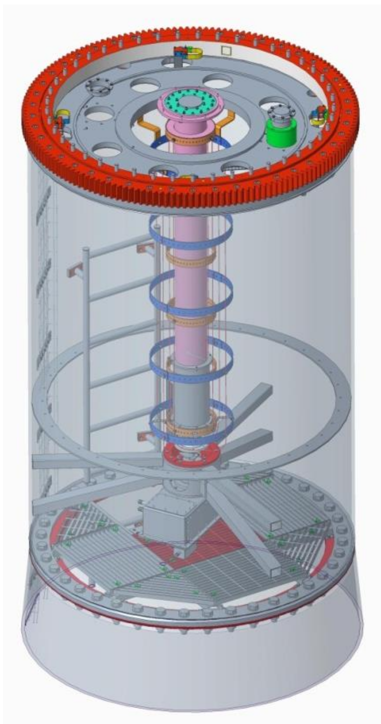


Figure 13: Overview of Middle Pedestal Section with Equipment

3) Upper Pedestal Section

The upper pedestal section is bolted to the middle pedestal section. It will be integrated with azimuth bearing, azimuth cable wrap, azimuth I/O unit assembly, azimuth stow assembly, brush slip-ring and other equipment, as shown in Figure 14.



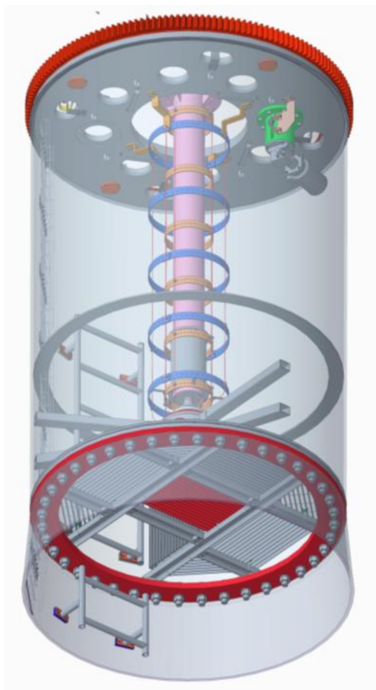


Figure 14: Overview of Upper Pedestal Section with equipment

The pedestal tower steel structure is shown in Figure 15.

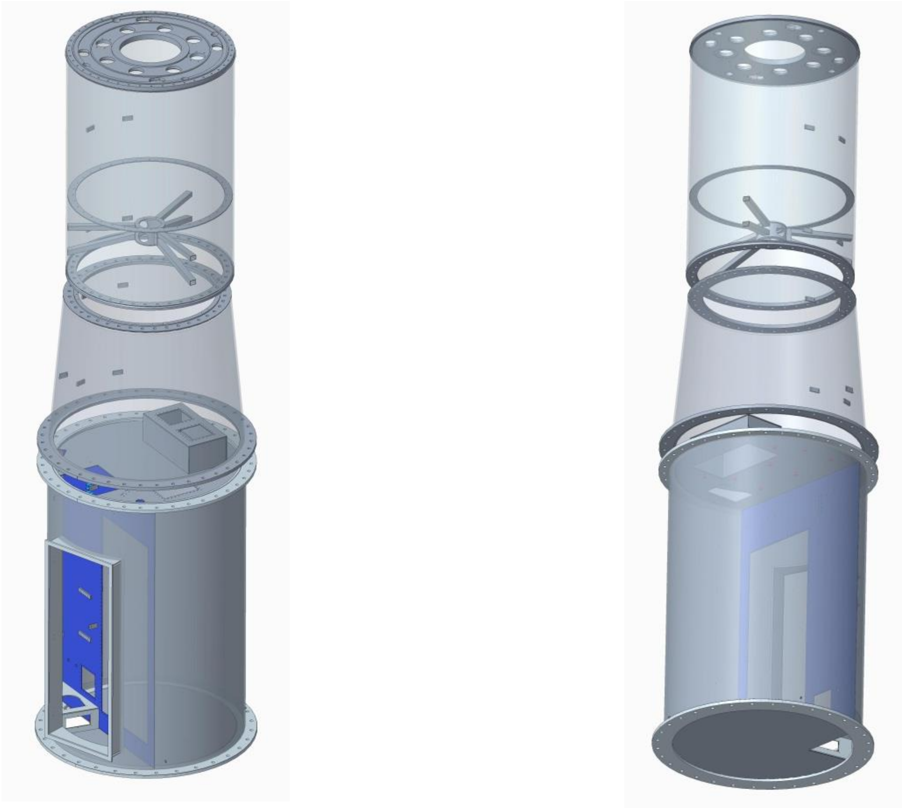


Figure 15: Pedestal Steel Structure

The pedestal tower is designed to provide the secure environment for the operators, maintenance staff as well as the equipment inside the pedestal.

- high stiffness floor and supporters
- locked door and grid guard
- air filter at inlet and outlet
- shield and sealed cover
- chamfered or covered edges and corners

3.2.2.2 Pedestal Shielded Compartment

The pedestal shielded compartment (PSC) is a steel seam welded enclosure to protect outside environment from electromagnetic interference. The PSC is integrated with lower pedestal section, applied with the required EMI shielding door, EMI shielding ventilation windows and EMI shielding penetrations for Cables & fibres as shown in the Figure 16 to Figure 19. The PSC provides the required EMI shielding, lightning protection zone and environmental protection to the dish electronic equipment and SaDT network equipment, which are housed in an additional EMI shielded cabinet separately.

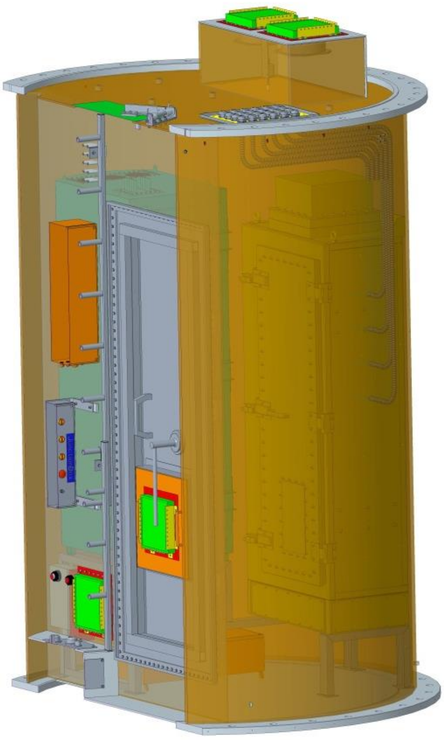


Figure 16: PSC Overview

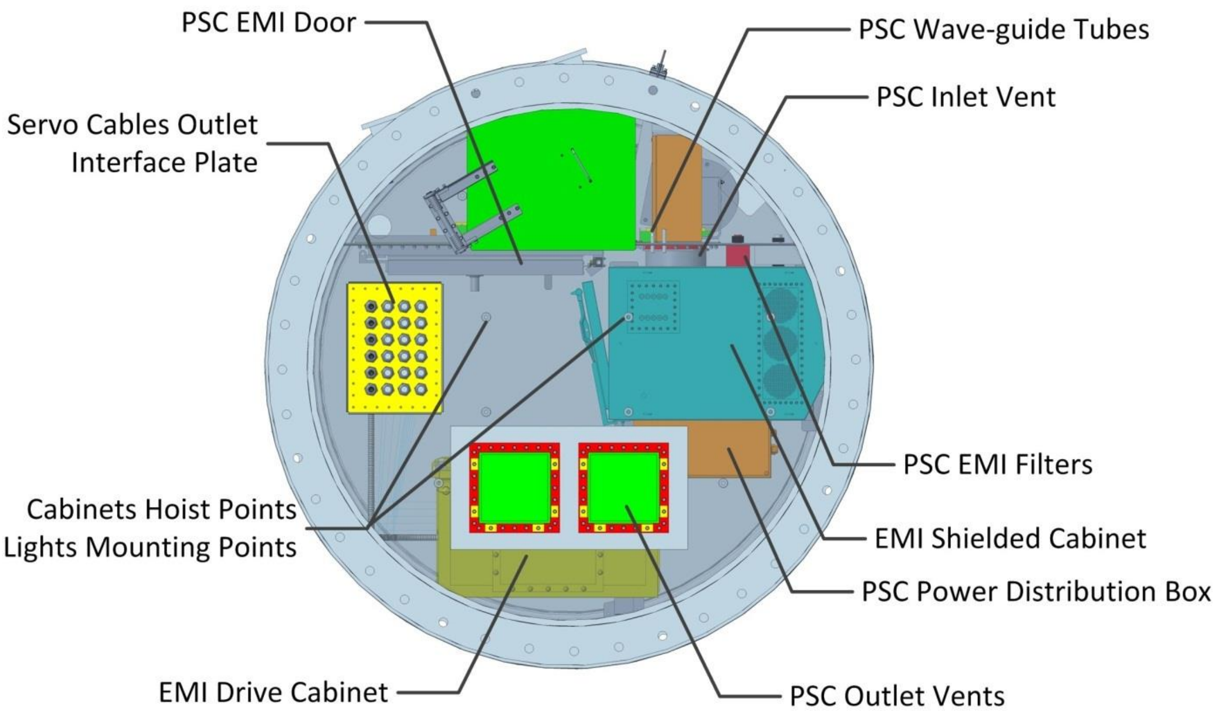


Figure 17: PSC Layout from Top

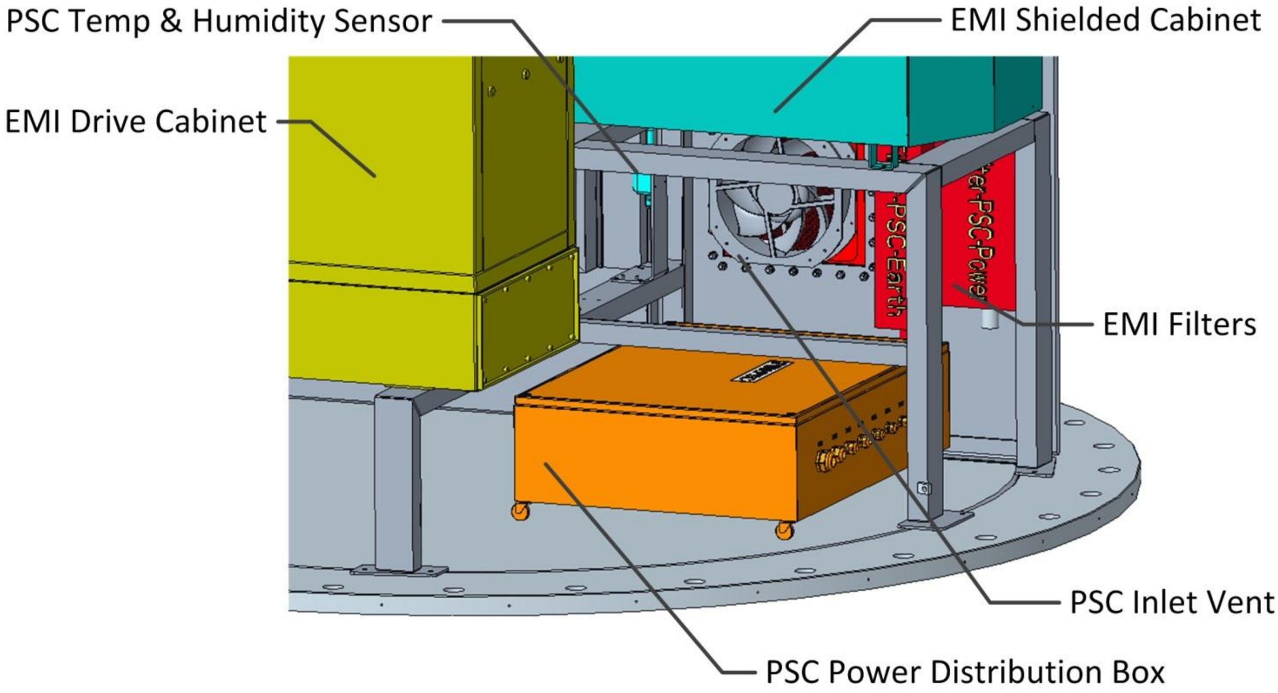


Figure 18: PSC Layout at Bottom

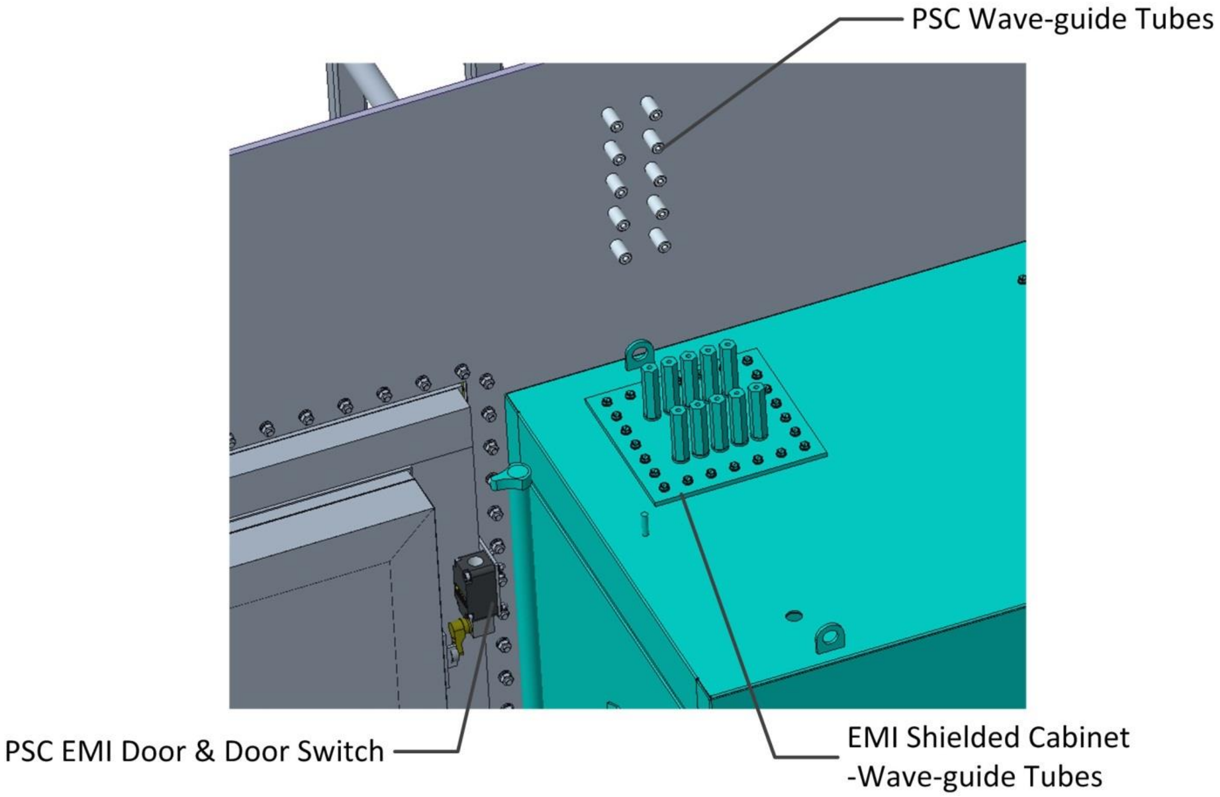


Figure 19: PSC Layout around Fibre Penetration

Two EMI filters are applied for penetration of power supply cable and earth cable separately. For the penetrations of fibres, the stainless fibre wave-guide tubes are welded onto the PSC wall above the EMISC. For the penetrations of Servo cables and fibres, a stainless plate is bolted onto the PSC ceiling with EMI gasket, above the drive cabinet. The plate will be integrated with the EMI metallic cable &

fibre conduits which are connected to the servo cabinet filters at the other end. The filters ensure that the output signals fulfil the EMI requirements and the EMI metallic conduits shield the signals inside the PSC.

All the ventilation components of PSC are equipped with wave-guide vent window. All the ventilation fans are mounted inside the PSC. The fan speed is non-variable, avoiding any additional EMI signal generated.

The layout inside PSC ensures enough space for doors opening and maintenance work of EMISC and servo cabinet. The PSC door is to be opened to the inside of the PSC. The cabinet doors are to be opened away from the entrance in view of emergency.

The clear dimensions of PSC door are 700 mm * 2300 mm, which allows all the cabinets moving in. The height of PSC is 3300 mm. There is 500 mm of height of spare space, where a electic hoist can be used for movement and installation of all cabinets inside the PSC.

The RFI shielding is established by the steel construction with suitable wall thickness and full seam welding joints. Stainless steel inserts are used at penetrations to allow for good grounding planes for filters and conduits without the risk of corrosion during its lifetime. The shielded door makes use of RFI finger stock that can be replaced should it get damaged during operation. More details will be illustrated in the section

3.2.2.3 EMI Shielded Cabinet (EMISC)

The EMISC has the following main functions:

- **Provide mounting,**
- **Provide EMI Shielding,**
- **Provide the required environmental conditions (air temperature) and**
- **Distribute power**

to the 3rd party equipment to be installed at the Dish. Refer to Table 1 for a list of the 3rd party equipment and a summary of the critical interface information as the time of design.

Table 1: List of equipment located inside the EMISC

Description	Height (U)	Depth (mm)	Mass (kg)	Power Consumption (W)	Heat Load (W)	Airflow direction	Airflow (cfm)
SPF Controller	1	220	3	50	50	NONE	NONE
SPFRx Receiver Pedestal Unit	6	450	18	200	200	Front - Back	75
DI PSC Fibre Routing Panel	3	360	6	0	0	NONE	NONE
LMC Hardware	2	480	11	150	150	Front - Back	130
SaDT STFR.FRQ Rx	3	475	4	50	50	Front - Back	100
SaDT STFR.UTC WR End Point	1	330	3.3	45	45	Front - Back	20
SaDT NSDN Switch	1	387	5.1	68	68	NONE	NONE
SaDT DDBH Node Switch	3	568	15	375	375	Front - Back	50
SaDT Patch Panel	2	360	4	0	0	NONE	NONE
PAF Controller	2	600	2	10	10	Front - Back	4
PAF Calibration Controller	2	600	2	10	10	Front - Back	4

The detail design and fabrication of the cabinet is done by ITC Services. The EMISC is located inside the Pedestal Shielded Compartment, refer to Figure 20. It is a 19inch profile EMI Shielded equipment cabinet with a rack capacity of ~40U, fabricated from stainless steel as a fully welded unit to provide optimum shielding performance. The overall size of the cabinet is approximately 2100mm x 650mm x 930mm (HxWxD). Refer to Figure 21.

The removal of the heat load is accomplished by forced airflow through the cabinet with the inlet at the bottom and the outlet, fitted with fans, at the top of the cabinet. Three 150mm fans, Papst 7856ES with a total airflow capacity of 573 cfm, are utilised. The ventilation openings are equipped with attenuvents to provide both airflow and EMI shielding.

Penetration for power through a 16 A 230VAC RFI filter on the power line, as well as 10 waveguide penetrations for the fibre control and monitor cables are provided. The inner diameter of the waveguides is 6mm with a length of 100mm to provide the required EMI shielding.

Power is distributed inside the cabinet by means of a commercial rack mounted PDU. The unit provides individual remote switching of individual outputs, as shown in Figure 22.

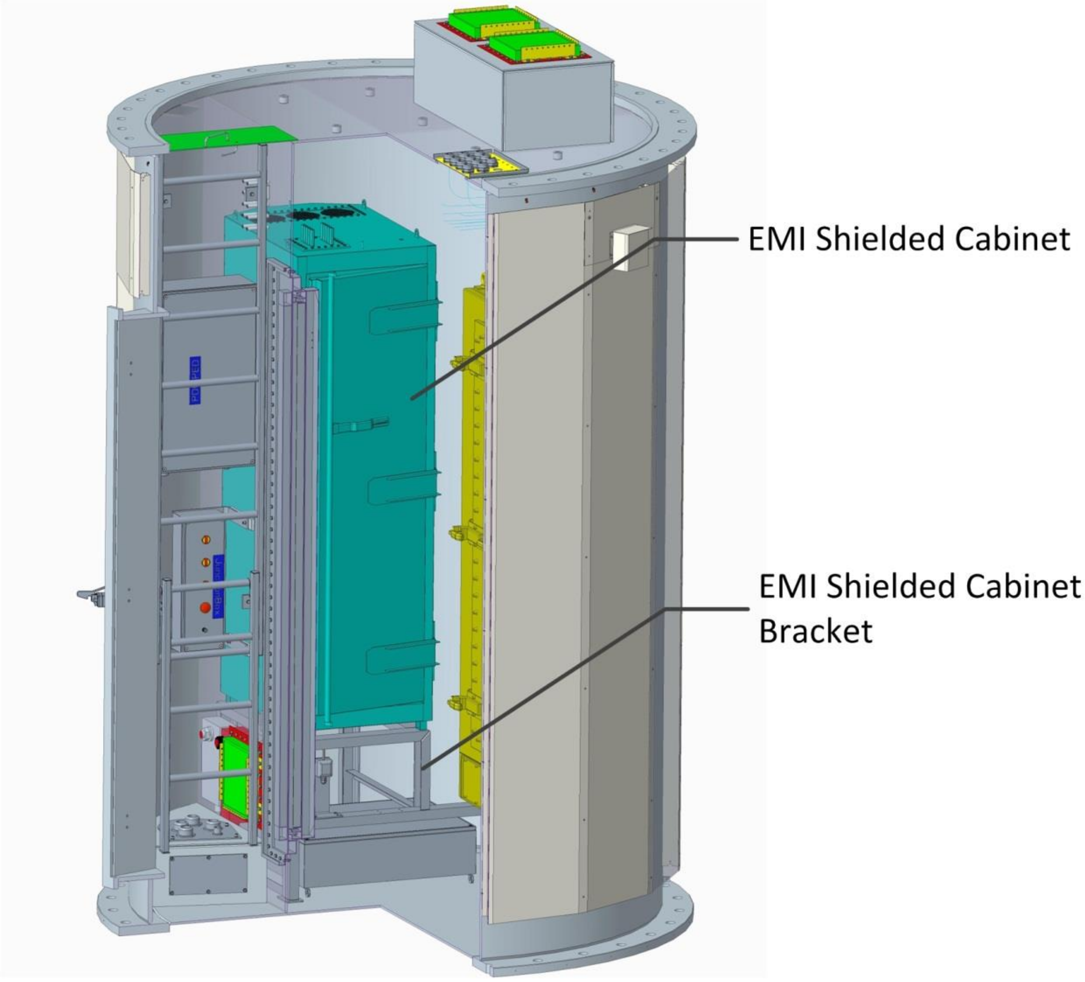


Figure 20: EMISC Location inside the PSC

Figure 21. EMISC

Figure 22. EMISC Power Distribution Unit

3.2.2.4 Azimuth Actuators

The gearbox is mounted on the bottom outside of the turnhead, whose gear is meshed with azimuth bull gear. The azimuth motor is directly connected with the gearbox. A cover is mounted outside the gearbox and the motor for anti-water. The azimuth gearbox and motor are shown in Figure 23.

The gearbox adopts sealed structure with grease inside. Generally, the service life of grease will be 10 years. The gearbox is considered as line replaceable unit, which can easily be replaced on-site and re-lubricated at the depot workshop.

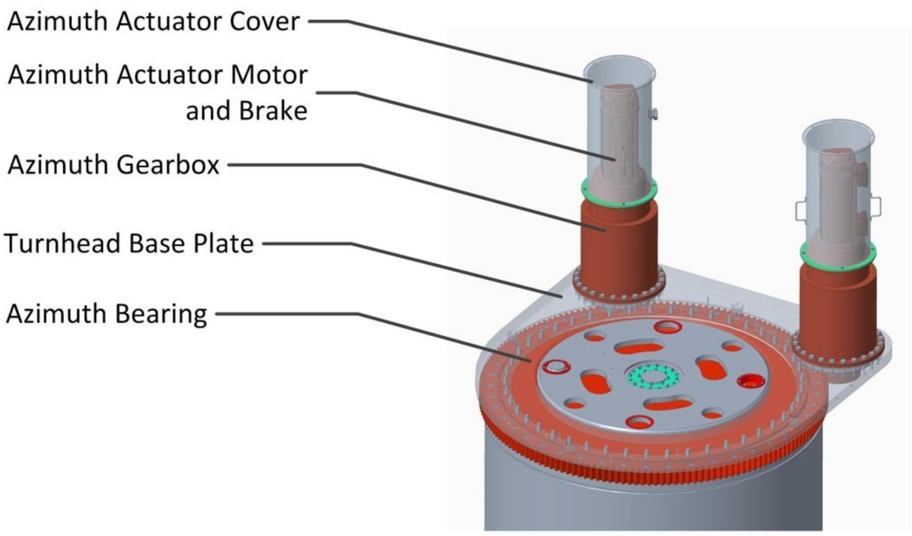


Figure 23: Azimuth Gearbox and Motor

The azimuth actuator is applied with a cover to protect the motor against the dust and rain, as shown in Figure 24. The cover allows the airflow from the bottom to the top.

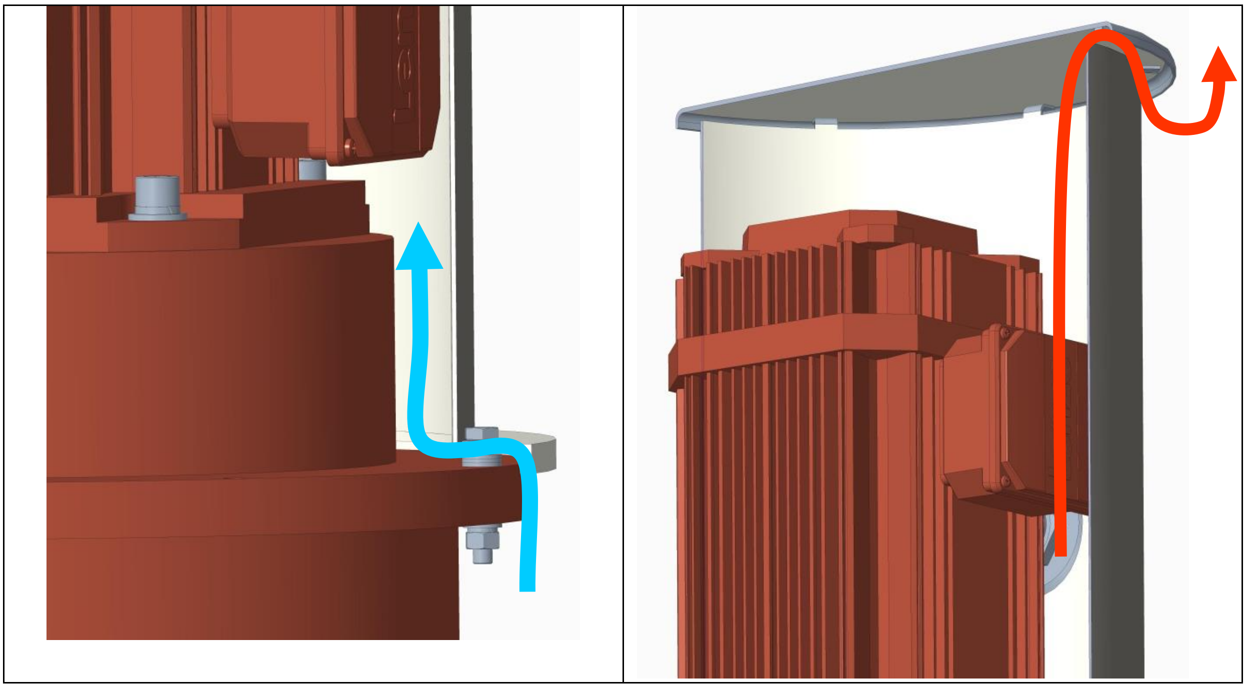


Figure 24: Azimuth Actuator Cover and Airflow

The azimuth actuators are required to provide backlash free turning torque to the azimuth axis, with sufficient stiffness and precision to meet the allocated pointing error budget and high efficiency to meet the power budget requirements. Two asynchronous servo motors drive via a planetary gear and pinion(s) to the azimuth gear rack the azimuth rotating parts of the telescope. The backlash is removed by operating the two motors with opposing torque. The torque bias concept is reported in Figure 25.

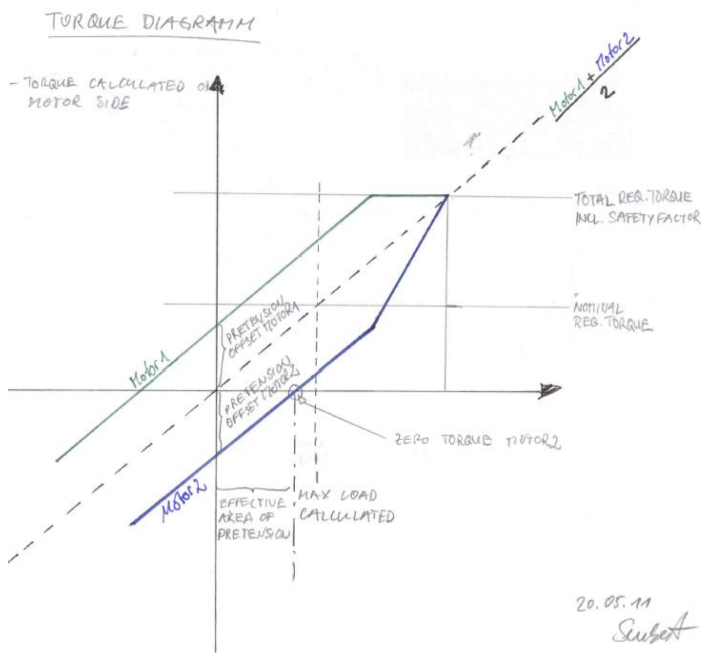


Figure 25: Pre-Tension of Two Motors to Eliminate the Backlash

The motor selected is Lenze, model MCA 21X25 EQNP1 with resolver and holding brake. Its main characteristics are:

- M_n: 24,6 Nm
- N_n: 2490 rpm
- P_N: 6,4kW
- M_{Brake}: 80Nm

The selection is based on the following torque budget values given in Table 2

Table 2 Azimuth Torque Budget

Azimuth		
given values		**comments and formulas**
Velocity maximum	3.5 °/s	spec + margin
Velocity tracking	0.050 °/s	
Acceleration maximum	3.50 °/s²	e-stop
Acceleration tracking	0.10 °/s²	
Weight	26,433 kg	FE model incl. margin
Friction factor µ	0.0055	
Radius of bearing	0.8 m	design
Inertia max	738,000 kgm²	FE model incl. margin
Inertia min	590,400 kgm²	Imin=Imax*0.8
Inertia of motor	0.02200 kgm²	AMK: DV10-44-4-RBF
Inertia of brake	0.00000 kgm²	incl. in motor
add. Loads	120,500 Nm	cfd analysis (20m/s wind) 120kNm cable drag = 500Nm
Ratio motor/axes	3,000.0	i_{gear}=300, i_{pinion}=10
Motors per axis	2.0	
calculated values axes		
Maximum acceleration load	69,272.1 Nm	$M_{acc,axis} = (J_{mount,max}+(J_{mot}*n_{mot}*i^2) +(J_{brake}*n_{brake}*i^2))*a_{max}*PI/180$
Friction loads	29,140.9 Nm	$M_{fric,axis}$ = weight*μ_{fric}*9,81*$r_{rail,aver.}$ + 2*14kNm gear friction
add. Loads	120,500 Nm	cfd analysis (20m/s wind) 120kNm cable drag = 500Nm
Total	**218,913.1 Nm**	$M_{total,axis} = M_{acc,axis} + M_{fric,axis} + M_{wind,axis}$
Tracking acceleration load	1,979.2 Nm	$M_{acc,axis} = (J_{mount,max}+(J_{mot}*n_{mot}*i^2) +(J_{brake}*n_{brake}*i^2))*a_{tracking}*PI/180$
Total during tracking	**151,620.1 Nm**	$M_{tracking,axis} = M_{acc,axis} + M_{fric,axis} + M_{wind,axis}$
values motors side (div by gear ratio and 2 motors)		
Maximum acceleration load	11.5 Nm	Macc = $M_{acc,axis} / i / n_{mot}$
Tracking acceleration load	0.3 Nm	Macc = $M_{acc,axis} / i / n_{mot}$
Friction loads	4.9 Nm	Mfric = fric_load / i / n_{mot}
add. Loads	20.1 Nm	Mwind = wind_load / i / n_{mot}
add. Safety factor torque (1.3)	10.9 Nm	Msafety = (Macc + Mfric + Mwind) * 1,3
Total requiered torque	**47.4 Nm**	$M_{acc} + M_{fric} + M_{wind} + M_{safety}$
Motor speed peak	1,750.00 rpm	
Motor speed tracking	25.00 rpm	

3.2.2.5 Azimuth I/O Unit and Mount

The azimuth I/O unit is an EMI enclosure where the azimuth encoder, limit switches, and other relevant devices are housed and shielded. It is located in the upper pedestal section, under the azimuth cable wrap and slightly above the fixed platform, as shown in Figure 26. The angle of the housing is modified to ensure the ladder space and the maintenance clearance.

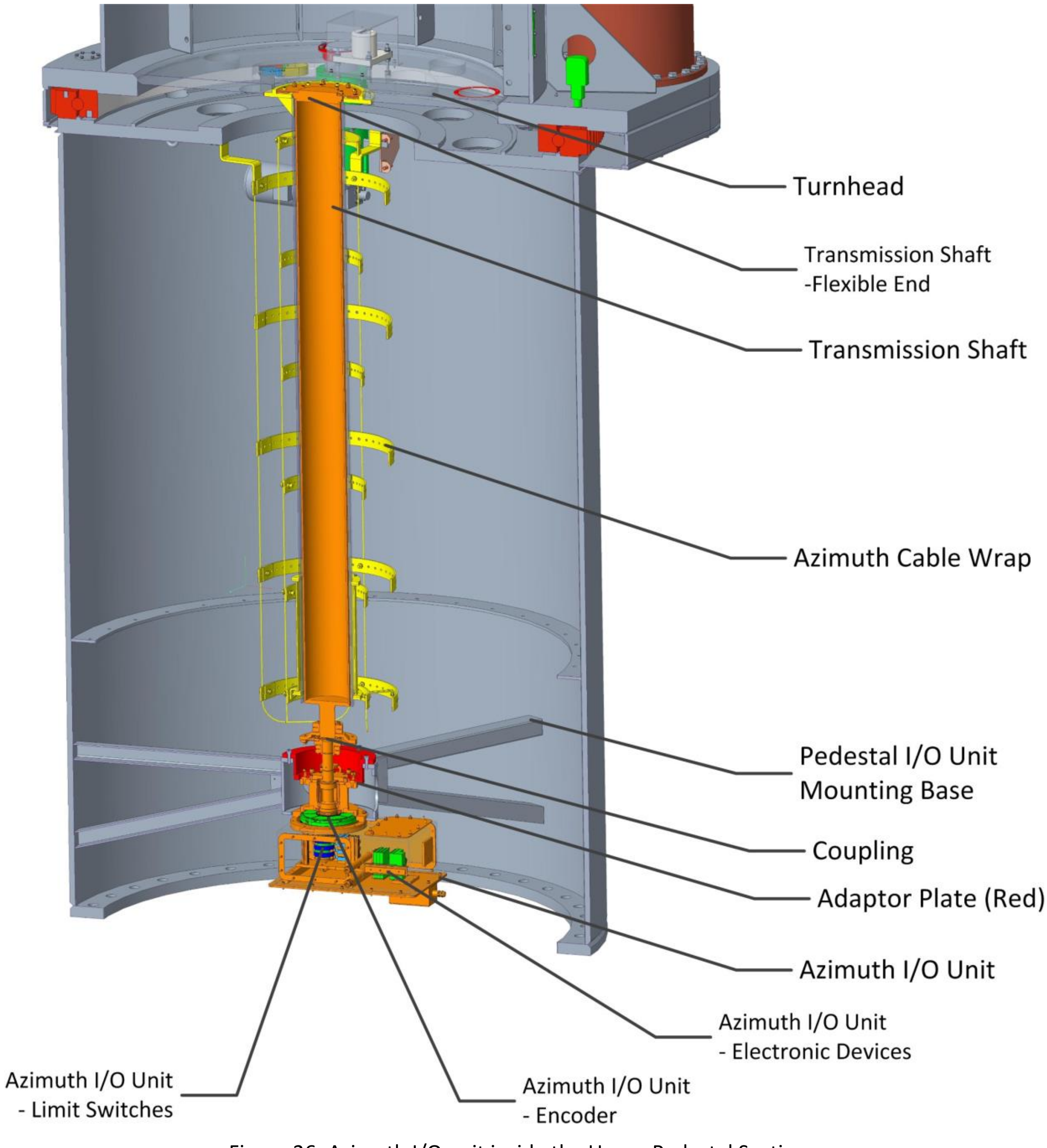


Figure 26: Azimuth I/O unit inside the Upper Pedestal Section

The mechanical transmission parts for the azimuth I/O unit consists of one coupling, transmission shaft, flexible end, pedestal I/O unit mounting base and adaptor plate.

As shown in Figure 27, The pedestal I/O unit mounting base is welded with the upper section pedestal and is machined to be in accordance with the azimuth bearing mounting base.

The adaptor plate is also machined precisely to ensure the perpendicularity of the encoder mounting interface. The base of azimuth I/O unit bearing will be mounted with the pedestal I/O unit mounting base through this adaptor plate. The adaptor plate allows slight alignment to achieve better coaxiality.

The lower layer of coupling is fixed on the azimuth cable wrap upper flange that is fixed on the turnhead. The upper layer of coupling is fixed with the top end flange of transmission shaft. The two layer plates are bonded with each other and transmit the rotation of turnhead to the shaft.

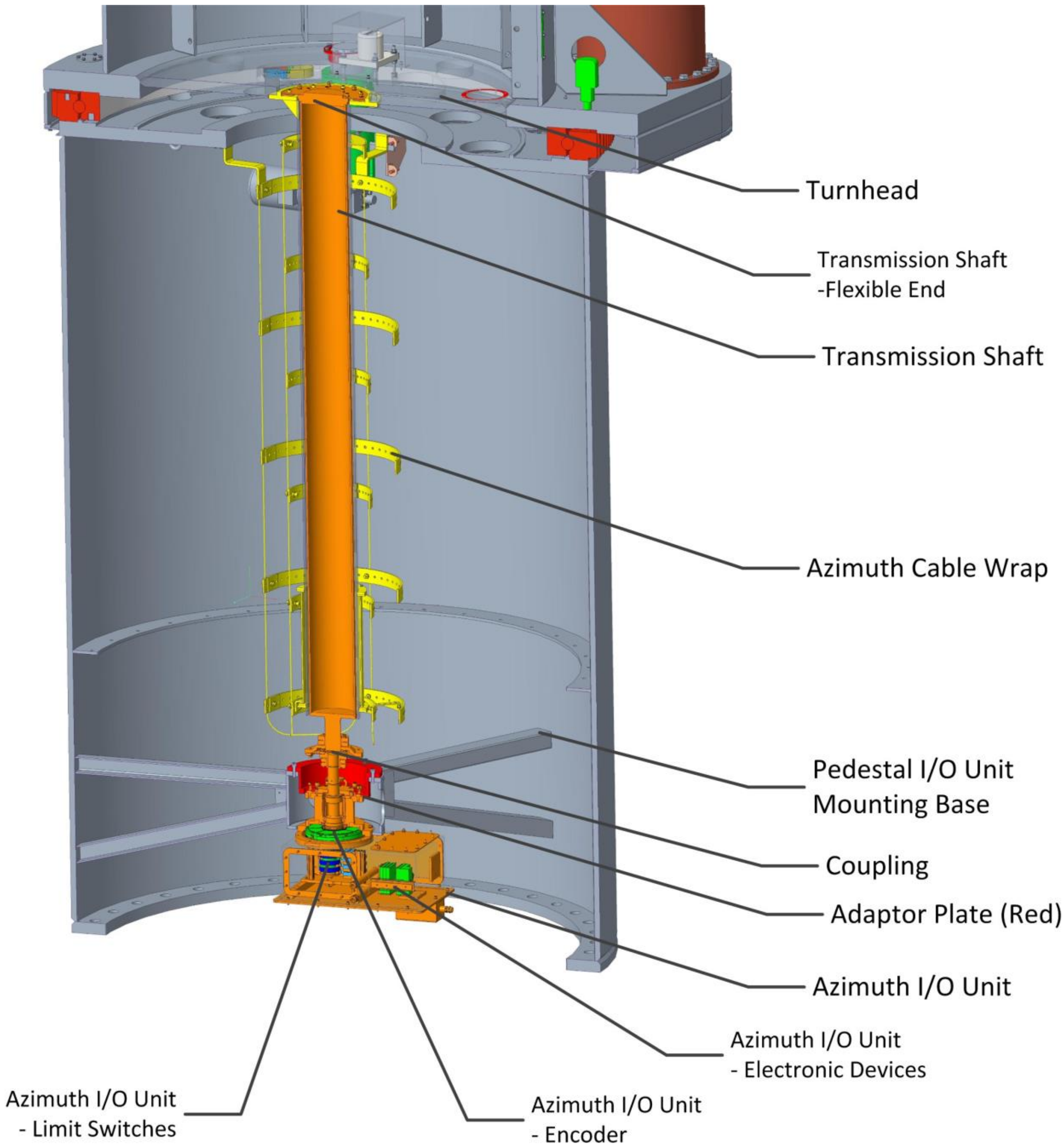


Figure 27 Azimuth I/O Unit Lower End Mounting

As shown in Figure 28, the shaft end of azimuth encoder is connected with the turnhead floor through the coupling, transmission shaft with one flexible end at opposite and the mounting flange of azimuth cable wrap.

The flexible end of the transmission plate uses twin plates to achieve the mechanism of diaphragm coupling.

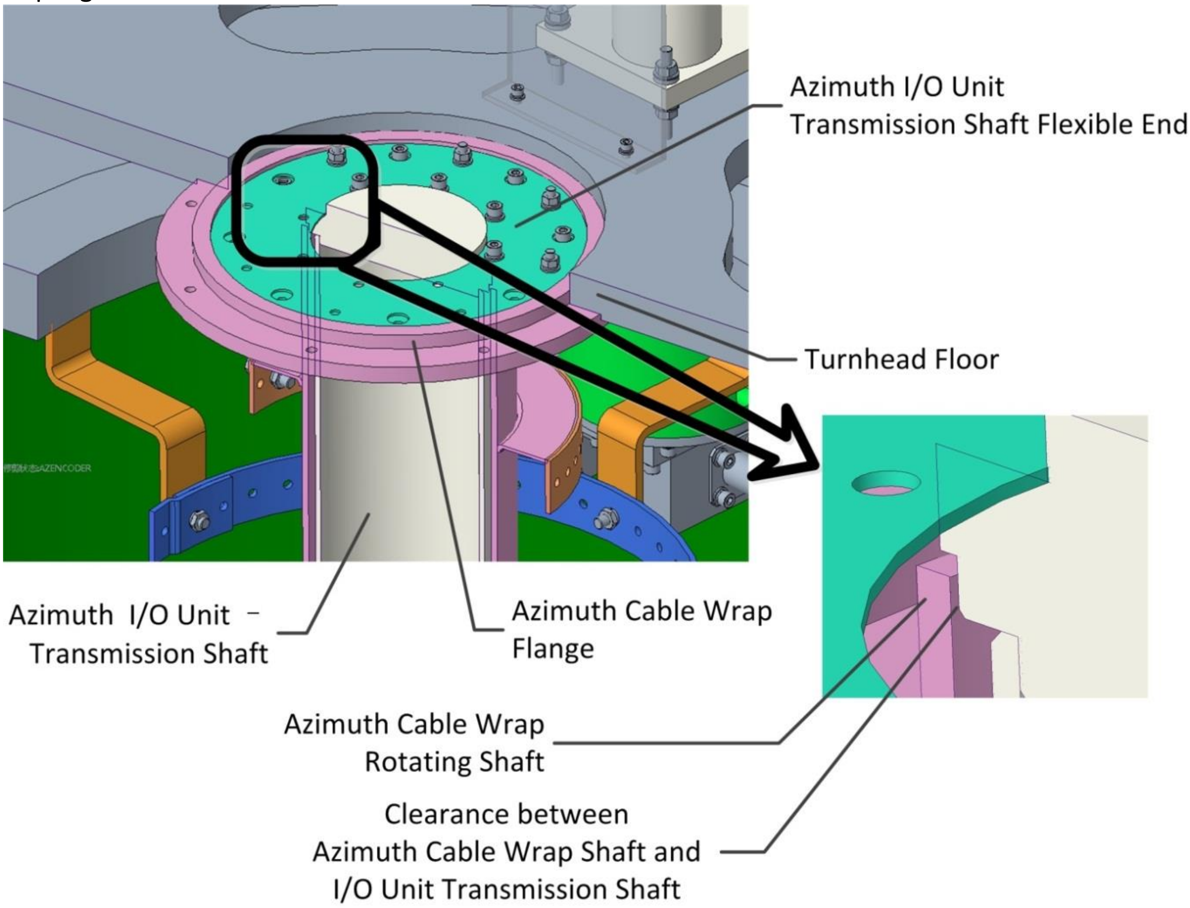


Figure 28: Azimuth I/O Unit Upper End Mounting

The position feedback is one of the main contributors to the overall performance of the telescope. Therefore the encoder is part of the telescopes overall error budget.

The encoder is installed directly on the main axis to measure as close as possible the true direct position of the telescope.

The encoder assembly not only provides the main axis position feedback, but also provides the final limit switches and emergency safety limit switches for the control and safety system. To reduce the risk of EMI disturbances to the outside, or other telescopes, the encoder assembly also contains the electronics required to read the necessary information leaving only fibre optic connection and 24VDC supply power to enter and exit the EMI shielded enclosure (see Figure 29 and Figure 215).

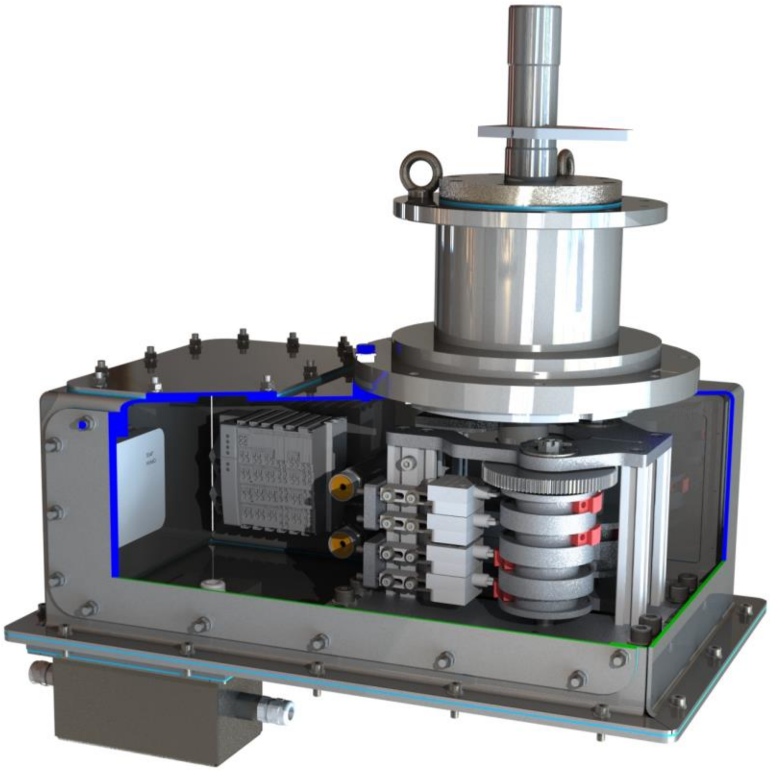


Figure 29: Encoder and Limit Switches Electronics

The connection between the encoder and azimuth bearing allows the precise transmission and easy replacement of encoder.
The azimuth encoder and limit switch structure are shown in given Figures below, composed of shaft, coupling, encoder mount, encoder, limit switch, gear, limit cam, etc. The limit switch allows pre-limit switch and final limit switch at ±270°.

Together with the manufacturer, MTM has chosen the encoder type to be the normal COTS encoder with the reduced friction due to the use of the labyrinth sealing. That is to improve the accuracy and performance during slow motion.
The high accuracy encoder system intrinsically provides the feedback as single turn (0° to 360°), with the additional sector switches, the revolution of the azimuth axis is determined and this enables the control system to derive an absolute position over the full range of travel.

Figure 30: Absolute Position Feedback Dr. Johannes Heindenhain, RCN8580

The envisioned manufacturer for SKA is Dr. Johannes Heidenhain GmbH (JH) from Traunreut, Germany. This company not only produces the most accurate position sensors for large telescopes, but also investigates the challenges and difficulties presented by such position sensors.

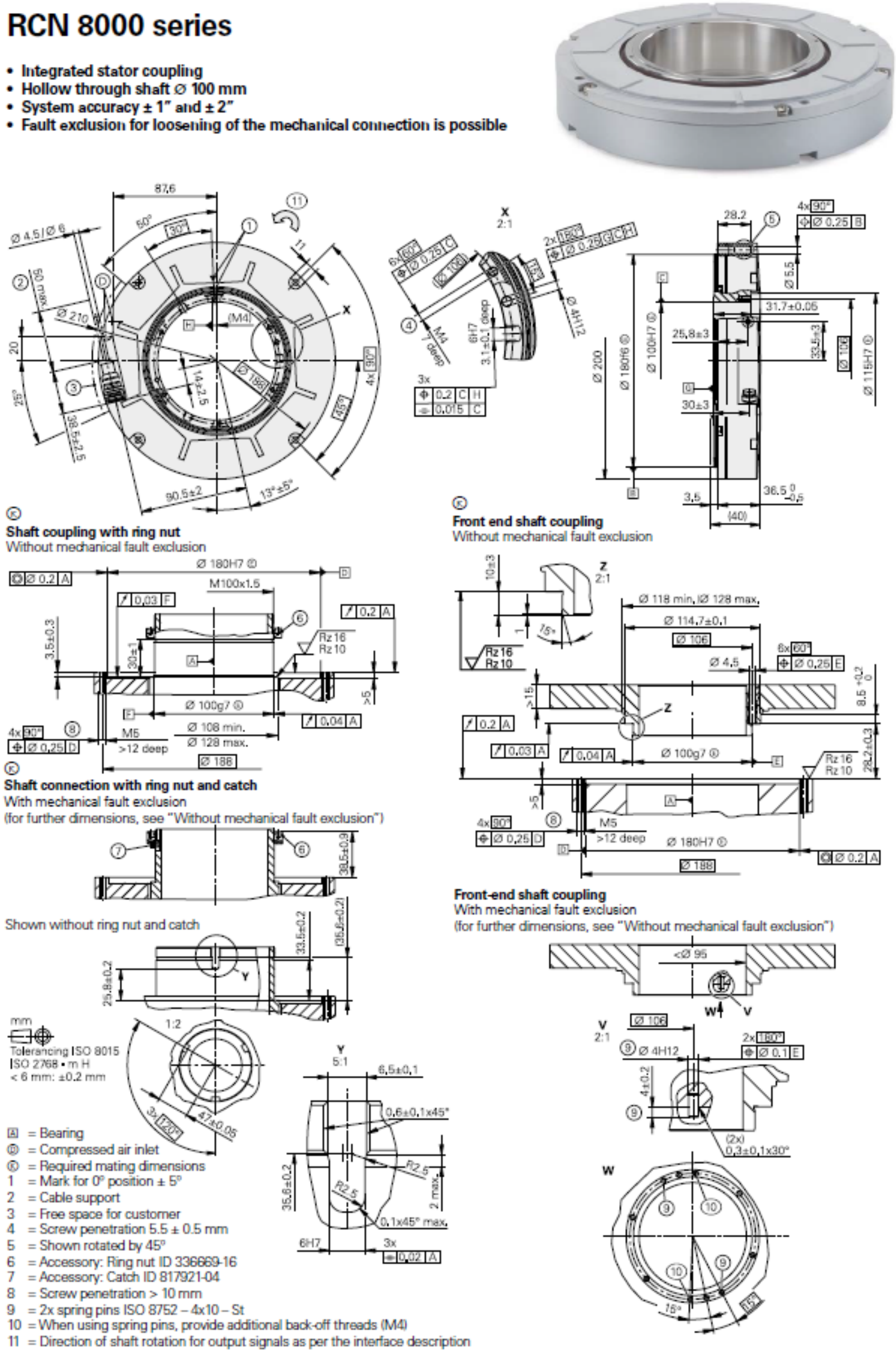
The provided performance requirements from [RD1] have been analysed and present challenging derived performance requirements for the encoder system itself. The accuracy requirements presented in 6.2 are ±1" as absolute accuracy. The selected encoder type is RCN8580, providing the required accuracy.

The datasheet and further information is provided below.

	Absolute **RCN 8510** **RCN 8310**	**RCN 8580** **RCN 8380**	**RCN 8590 F** **RCN 8390 F**	**RCN 8590 M** **RCN 8390 M**
Measuring standard	DIADUR circular scale with absolute and incremental track (32 768 lines)			
System accuracy	*RCN 85x0:* ± 1"; *RCN 83x0:* ± 2"			
Position error per signal period	*RCN 85x0:* ≤ ± 0.15" *RCN 83x0:* ≤ ± 0.2"	*RCN 85x0:* ≤ ± 0.2" *RCN 83x0:* ≤ ± 0.2"		
Functional safety*	Option[1]	–		
Interface	EnDat 2.2		Fanuc serial interface αi Interface	Mitsubishi high speed interface
Ordering designation	EnDat22	EnDat02	Fanuc05	Mit03-4
Position values/revolution	536 870 912 (29 bits); *Fanuc α Interface:* 134 217 728 (27 bits)			
Elec. permissible speed	≤ 1500 min^{-1} for continuous position value	≤ 750 min^{-1} for continuous position value	≤ 1500 min^{-1} for continuous position value	
Clock frequency Calculation time t_{cal}	≤ 16 MHz ≤ 5 µs	≤ 2 MHz ≤ 5 µs	–	
Incremental signals Cutoff frequency –3 dB	–	∼ 1 V_{PP} ≥ 400 kHz	–	
Electrical connection	Separate adapter cable connectable to encoder via quick disconnect			
Cable length[2]	≤ 150 m		≤ 50 m	≤ 30 m
Voltage supply	3.6 V to 14 V DC			
Power consumption[3] (max.)	*3.6 V:* ≤ 1.1 W; *14 V:* ≤ 1.3 W			
Current consumption (typical)	*5 V:* 140 mA (without load)			
Shaft	Hollow through shaft D = 100 mm			
Mech. permissible speed	≤ 500 min^{-1}; *temporary:* ≤ 1500 min^{-1} [4] (Speeds over 500 min^{-1} require consultation)			
Torque (friction)	≤ 4.5 Nm (typical starting torque: ≤ 1.0 Nm at 20 °C)			
Moment of inertia	*Rotor (hollow shaft):* 3.20 · 10^{-3} kgm^2; *Stator (housing/flange):* 10.0 · 10^{-3} kgm^2			
Permissible axial motion of measured shaft	± 0.3 mm			
Natural frequency	≥ 900 Hz			
Vibration 55 to 2000 Hz **Shock** 6 ms	≤ 200 m/s^2 (EN 60 068-2-6) ≤ 200 m/s^2 (EN 60 068-2-27)			
Operating temperature	0 °C to +50 °C			
Protection EN 60 529	IP 64			
Weight	≈ 2.6 kg			

* Please indicate when ordering
[1] For dimensions and specifications, see separate Product Information document
[2] With HEIDENHAIN cable; ≤ 8 MHz
[3] See *General electrical information* in the catalog *Interfaces of HEIDENHAIN Encoders*
[4] For mechanical fault exclusion, see page 21

Figure 31: Encoder Datasheet Page One



RCN 8000 series

- Integrated stator coupling
- Hollow through shaft ∅ 100 mm
- System accuracy ± 1" and ± 2"
- Fault exclusion for loosening of the mechanical connection is possible

Shaft coupling with ring nut
Without mechanical fault exclusion

Front end shaft coupling
Without mechanical fault exclusion

Shaft connection with ring nut and catch
With mechanical fault exclusion
(for further dimensions, see "Without mechanical fault exclusion")

Shown without ring nut and catch

Front-end shaft coupling
With mechanical fault exclusion
(for further dimensions, see "Without mechanical fault exclusion")

mm
Tolerancing ISO 8015
ISO 2768 - m H
< 6 mm: ±0.2 mm

Ⓐ = Bearing
Ⓓ = Compressed air inlet
Ⓚ = Required mating dimensions
1 = Mark for 0° position ± 5°
2 = Cable support
3 = Free space for customer
4 = Screw penetration 5.5 ± 0.5 mm
5 = Shown rotated by 45°
6 = Accessory: Ring nut ID 336669-16
7 = Accessory: Catch ID 817921-04
8 = Screw penetration > 10 mm
9 = 2x spring pins ISO 8752 – 4x10 – St
10 = When using spring pins, provide additional back-off threads (M4)
11 = Direction of shaft rotation for output signals as per the interface description

Figure 32: Encoder Datasheet Page Two

3.2.3 Turnhead

The turnhead consists of turnhead welded assembly and turnhead hatch assembly.
The key function of turnhead is to provide a sufficiently stiff rotatable elevation axis, an interface to the elevation assembly, mounting provisions for azimuth actuators, elevation actuator, elevation I/O unit assembly, helium compressor and ancillary components as shown in Figure 33 and Figure 34.

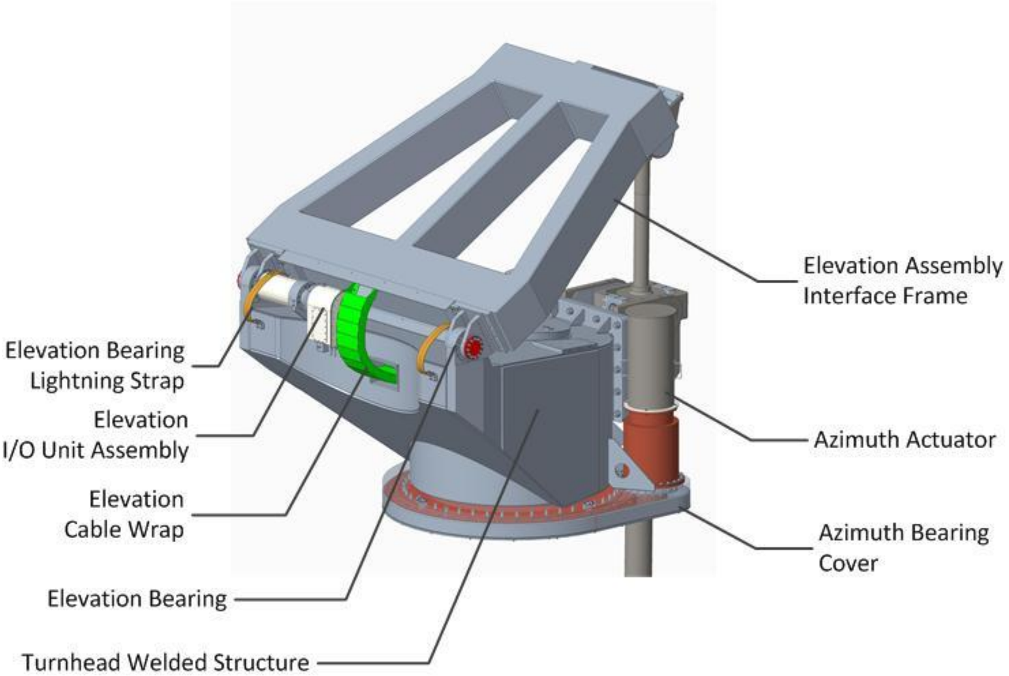


Figure 33: Overview of Turnhead Assembly (Front)

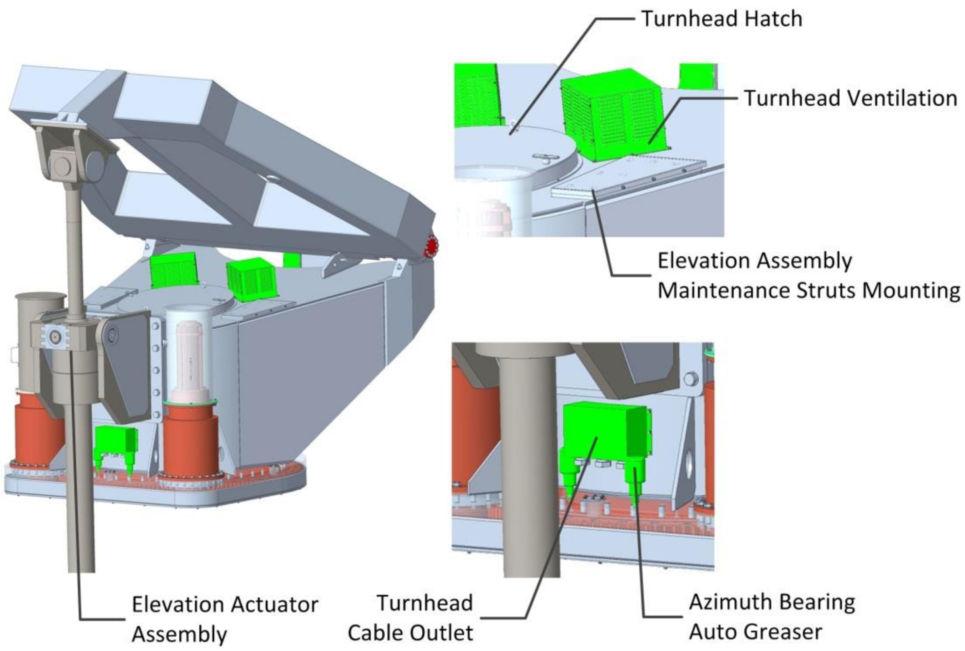


Figure 34: Overview of Turnhead Assembly (Rear)

3.2.3.1 Turnhead Steel Structure

The turnhead steel structure provides a structural connection between the azimuth and elevation bearings and provides the mounting interface to azimuth and elevation actuators. The mounting interface of bearings, actuators and encoders, etc., are precisely machined, as shown in Figure 35.

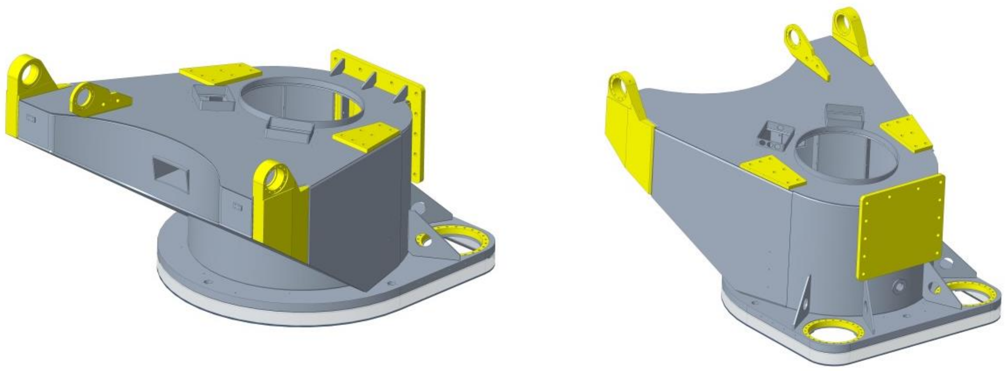


Figure 35: Turnhead Steel Structure

3.2.3.2 Elevation Actuator

The elevation actuator is mounted with its bracket interface to the machined turnhead interface. It consists of motor incl. brake, ball screw, ball screw mount, and cover etc., shown in Figure 36. The brake at the end of motor can lock the elevation at any position.

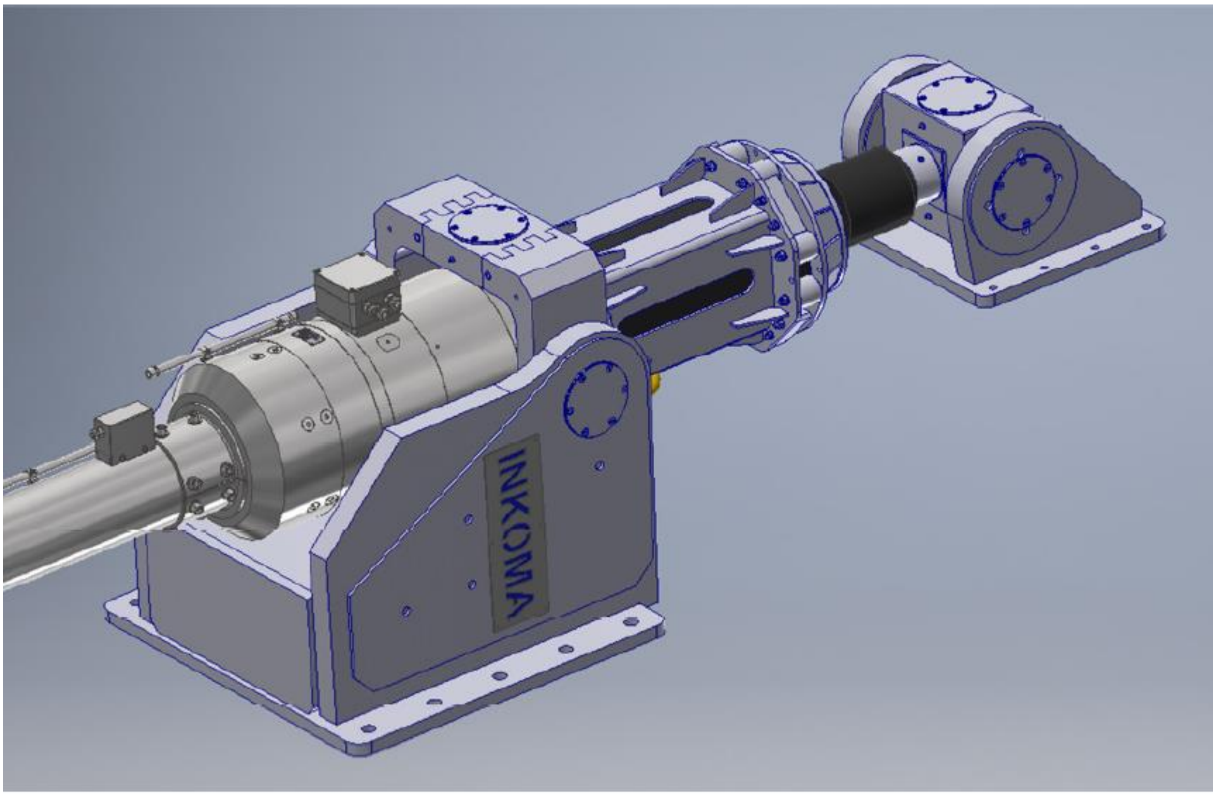


Figure 36: Elevation Actuator Overview

A rubber bellow unit protects for the upper part of jack. The general service time of the rubber bellow under the sunshine is 3-4 years. The rubber bellow unit is designed as line-replaceable unit for easy on-site maintenance.
The elevation assembly shall be parked during maintenance and survival wind in the fully compressed position of the Jack screw (El ≈ 92°). Special mechanical tooling (second load path actuators) and interfaces keep the elevation assembly in place during maintenance or replacement of the actuator. These mechanical Actuators will be installed only temporary.

At the upper/moving end, a backlash-free ball joint with a pre-stressed bolt has been designed. The lower/stationary end is a flange with a definite bolt circle, as shown in Figure 37

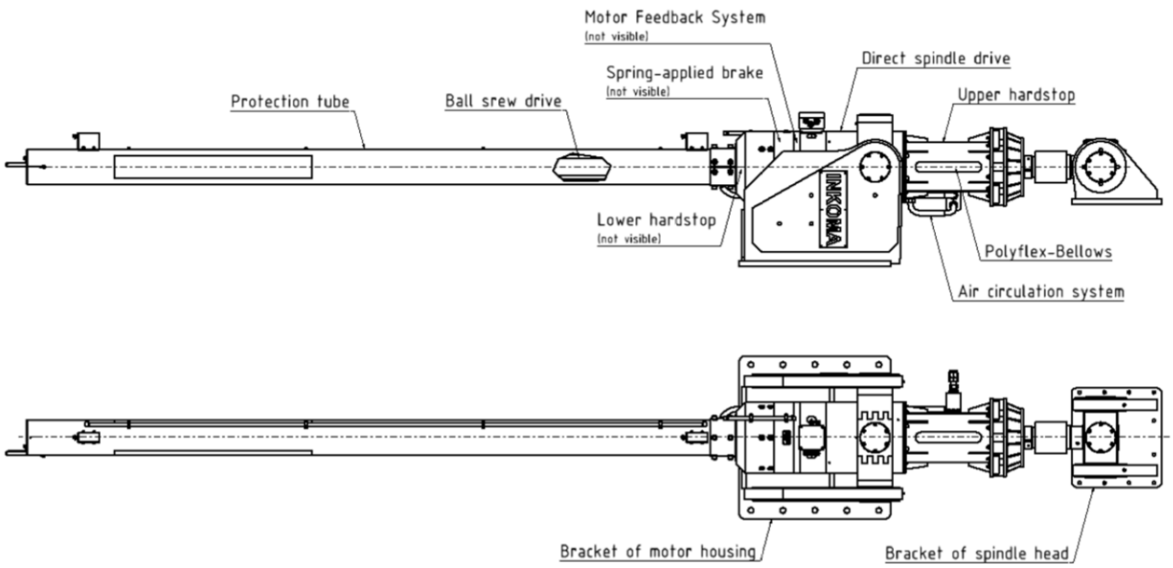


Figure 37 Upper and Lower Mechanical Interface to Structure Overview

The actuator is specified with more details in [RD1], some general topics are mentioned and explained below.
The elevation actuator geometry results in a varying ratio between elevation axis and motor axis, this geometry is given in Figure 38 with the resulting overall transmission plot in Figure 39.

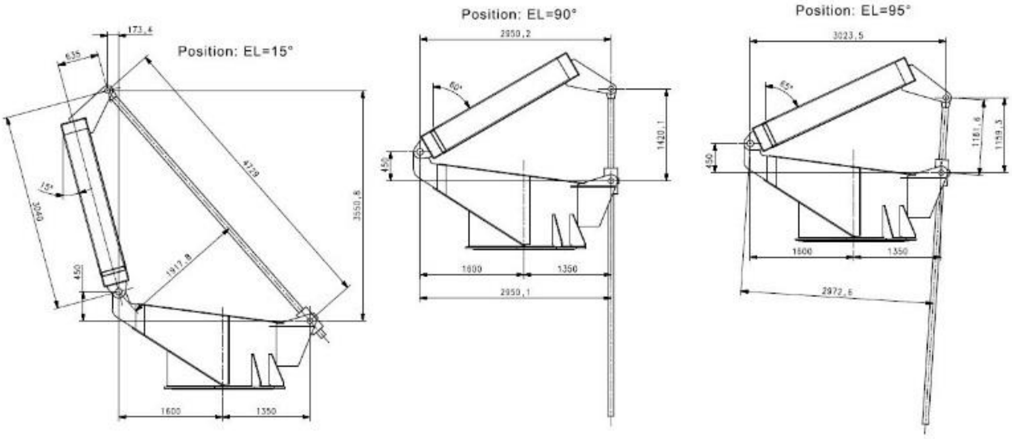


Figure 38: Elevation Axis Geometry

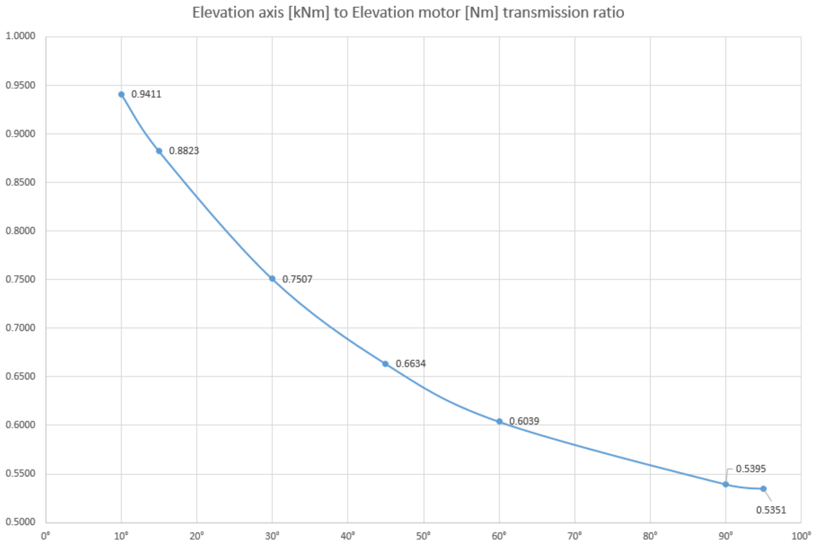


Figure 39: Elevation Transmission Ratio Total

The Jack Screw hollow shaft is a torque motor that can generate high torques at relatively low speeds. It consists of the stator with three windings, the rotor with the attached permanent magnets (pole pairs) and two temperature-monitoring circuits.
The motor data can be found in the following table.

Technische Daten	Symbol	Einheit	Wert
Nominal torque (not cooled, air convection)	M_n	Nm	303
Nominal current (not cooled, air convection)	I_n	A_{eff}	18,3
Nominal speed (without field weaking))	n_n	min^{-1}	380
Standstill / Holding torque	M_{halt}	Nm	224
Standstill / Holding current	I_{halt}	A_{eff}	13,5
Peak torque (1s)	M_p	Nm	320
Peak current (1s)	I_p	A_{eff}	19,4
Torque constant	kM	Nm/A_{eff}	16,5
Voltage constant (phase to phase)	ku	Vs/rad	13,5
Resistance (phase to phase) at 25°C	R_{Ph25}	Ω	0,86
Inductance (phase to phase)	L_{Ph}	mH	9
DC link voltage	U_{Zk}	V	600
Number of pol pairs	2P	Stück	22
Max. winding temperature	T	°C	120

Figure 40: Hollow Shaft Motor data

The jack outer diameter is 100mm providing enough strength in park position (El ≈ 90°) and in combination with the special designed buffer system to withstand the survival wind loads.

Type	Ball screw with nut
Dimensions	100 x 10 mm
Thread length	4900 mm
Load factor dynamic	146,2 kN
Load factor static	762,0 kN
Tolerance class	3

The Jack Screw brake works as a holding brake with emergency brake function. It is a failsafe, electromagnetic spring-applied brakes. When de-energized, the brake is active. That means the brake discs are applied, the braking torque acts on the spindle nut and the ball screw is held in the respective position. In the event of unexpected failure of the motor control or power failure the terminal box of the Jack Screw drive, the brake acts as an emergency brake and brakes the ball screw spindle unit it stops.

The Jack screw has an air circulation systems which sucks clean air from inside the Pedestal / Turnhead Assembly. The Air circulation system ventilates the bellows and the protective tube.

Further information like:

- 11690_Assembly instruction_DSH_132985-002_06-2018_EN
- 11690_Lubrication DSH_132985-002_06-2018_EN
- 11690_Operating instruction_DSH_06-2018_EN

can be found in the reference documents.

3.2.3.3 Elevation Encoder and Limit Switch Structure

The elevation I/O unit is an EMI enclosure where the elevation encoder and limit switches are housed and shielded, located along the elevation axis outside the turnhead, as shown in Figure 41.

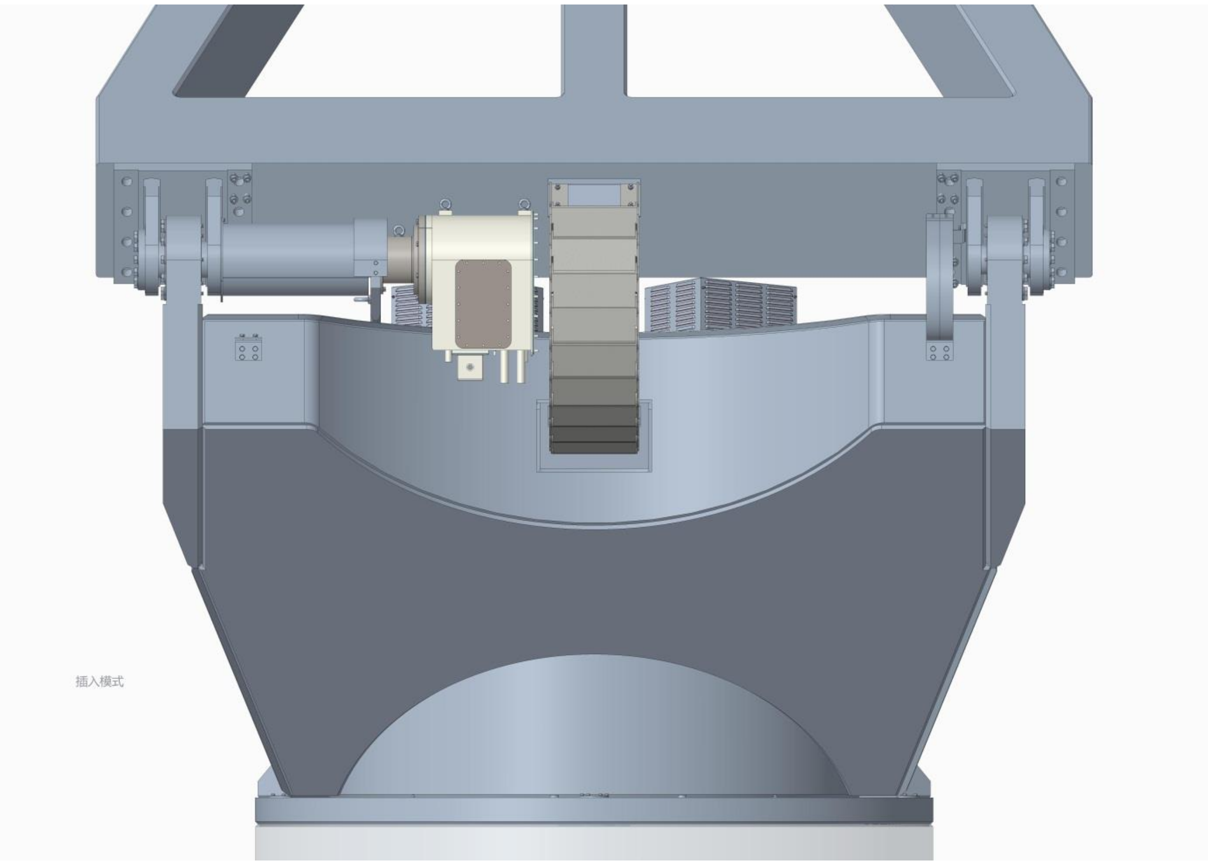


Figure 41: Elevation I/O Unit Mounted on the Turnhead

The mechanical transmission parts for the elevation I/O unit consists of two couplings, transmission shaft, turnhead I/O unit mounting base and elevation pin shaft, as shown in Figure 42.

The turnhead I/O unit mounting base is welded with the turnhead and the mounting interface is machined to be in accordance with the elevation bearing mounting base. The base of I/O unit bearing will be mounted directly with the turnhead I/O unit mounting base.

The shaft end of elevation encoder is connected with the elevation assembly through the couplings, transmission shaft with two couplings at the ends and the elevation pin shaft fixed on to the elevation assembly interface frame, as shown in Figure 43.
The elevation I/O unit is designed for outdoor conditions. The transmission shaft is applied with a cover to protect the EMI seals of the encoder shaft.

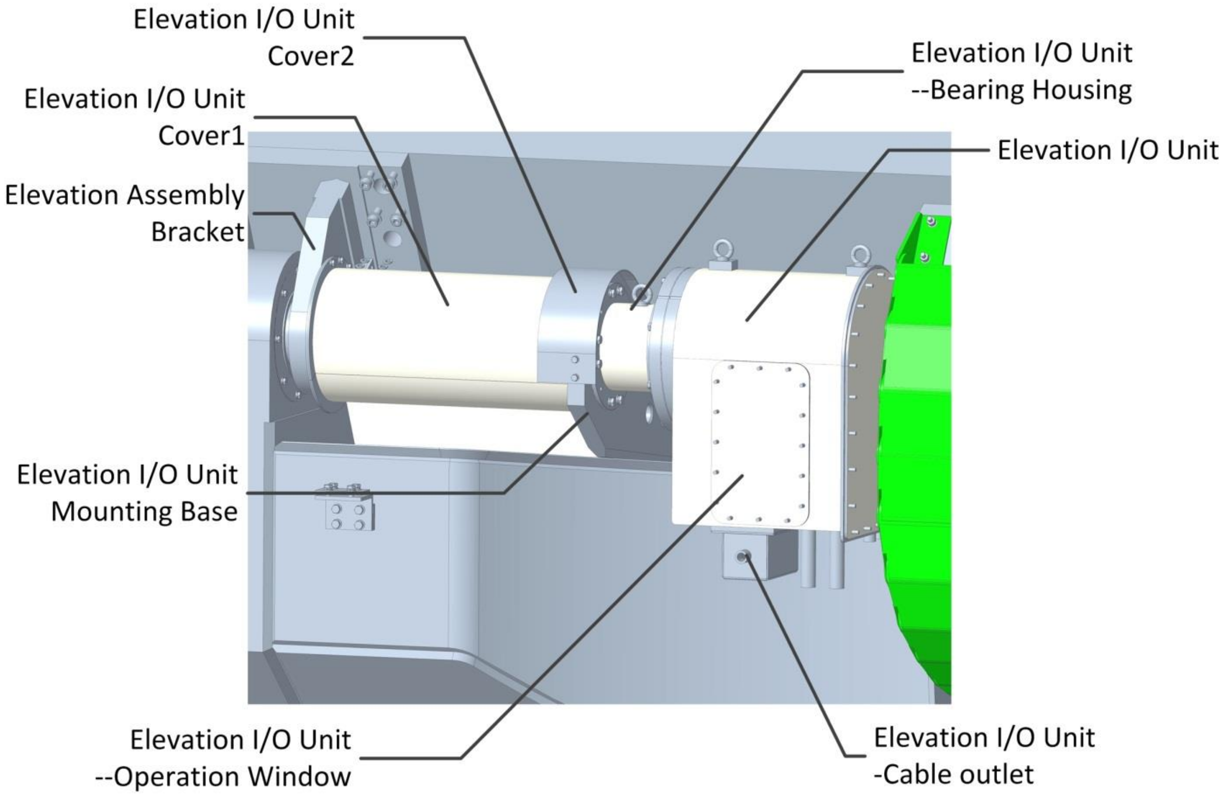


Figure 42 Elevation I/O Unit Mounting

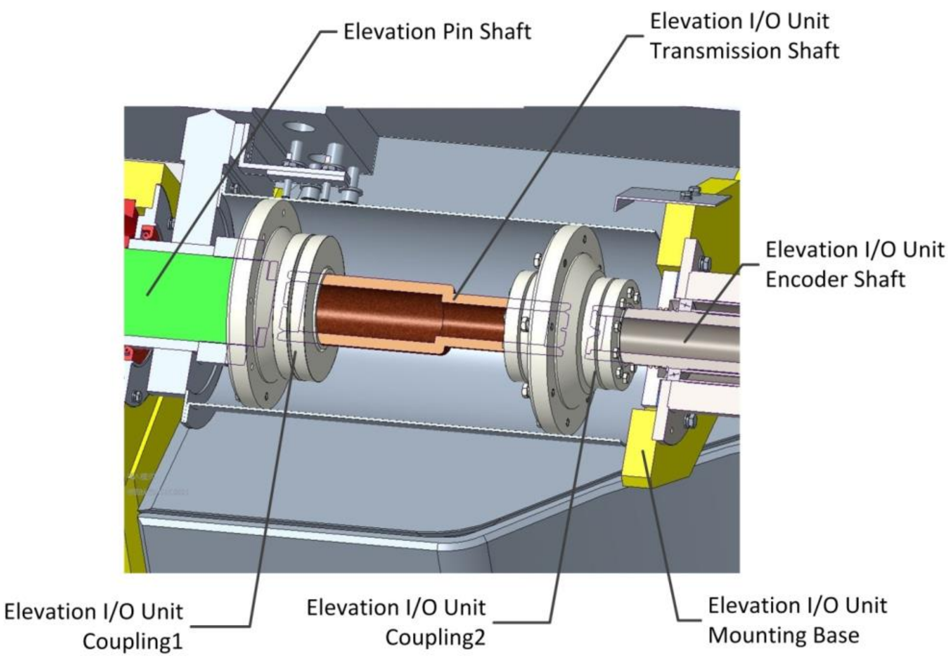


Figure 43: Elevation I/O Unit Shaft Transmission

Figure 44: Elevation I/O Unit

The elevation encoder system (elevation I/O unit assembly) consists of elevation encoder, elevation limit switch unit, I/O unit, temperature & humidity sensors, filters, and enclosure. The elevation limit switch unit consists of limit cams with limit switches. The enclosure is equipped with operation window for limit switch alignment and device maintenance.

The limit switch will be triggered at the elevation angles of 14°, 15°, 90° and 92°. The connection between the encoder and elevation bearing allows the precise transmission and easy replacement of encoder.

3.2.4 Elevation Assembly

3.2.4.1 General

Elevation Assembly adopts PSM structure which consists of main reflector, subreflector and support arm etc. The PSM ('Panelled Space frame-supported Metal') solution has the following features:

- good in stiffness and high in accuracy
- anti-creep deformation and well in durability
- high manufacturing accuracy, easy in fabrication and relative in low-cost
- easy in transportation
- fabricated in factory and installed on site
- good in environment durability

According to the optics data, the geometry is shown in Figure 45. The projected aperture of the main reflector is 15,000 mm, the subreflector major axis is 4,579mm; its geometry parameters are shown in Table 3.

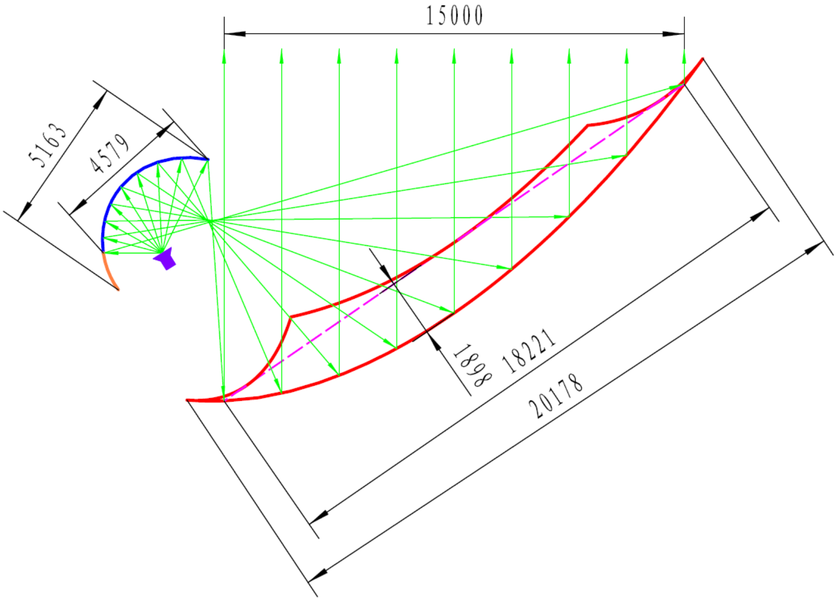


Figure 45: Geometry of Optics Design

Table 3: Dish Geometry Parameters

Name	Items	Parameter
Main Reflector	Major Axis (mm)	18221
	Minor Axis (mm)	15000
	Effective Curved Surface Area (m^2)	226.46
	Curved Surface Area (m^2)	252.87
Subreflector	Major Axis (mm)	4579
	Minor Axis (mm)	4333
	Effective Curved Surface Area (m^2)	20.27
	Extension Surface Area (m^2)	9.89

As shown in Figure 46, the optical path will be kept free of any part of the structure (excluding the active feed) with a minimum clearance of 430 mm to all direct ray paths.

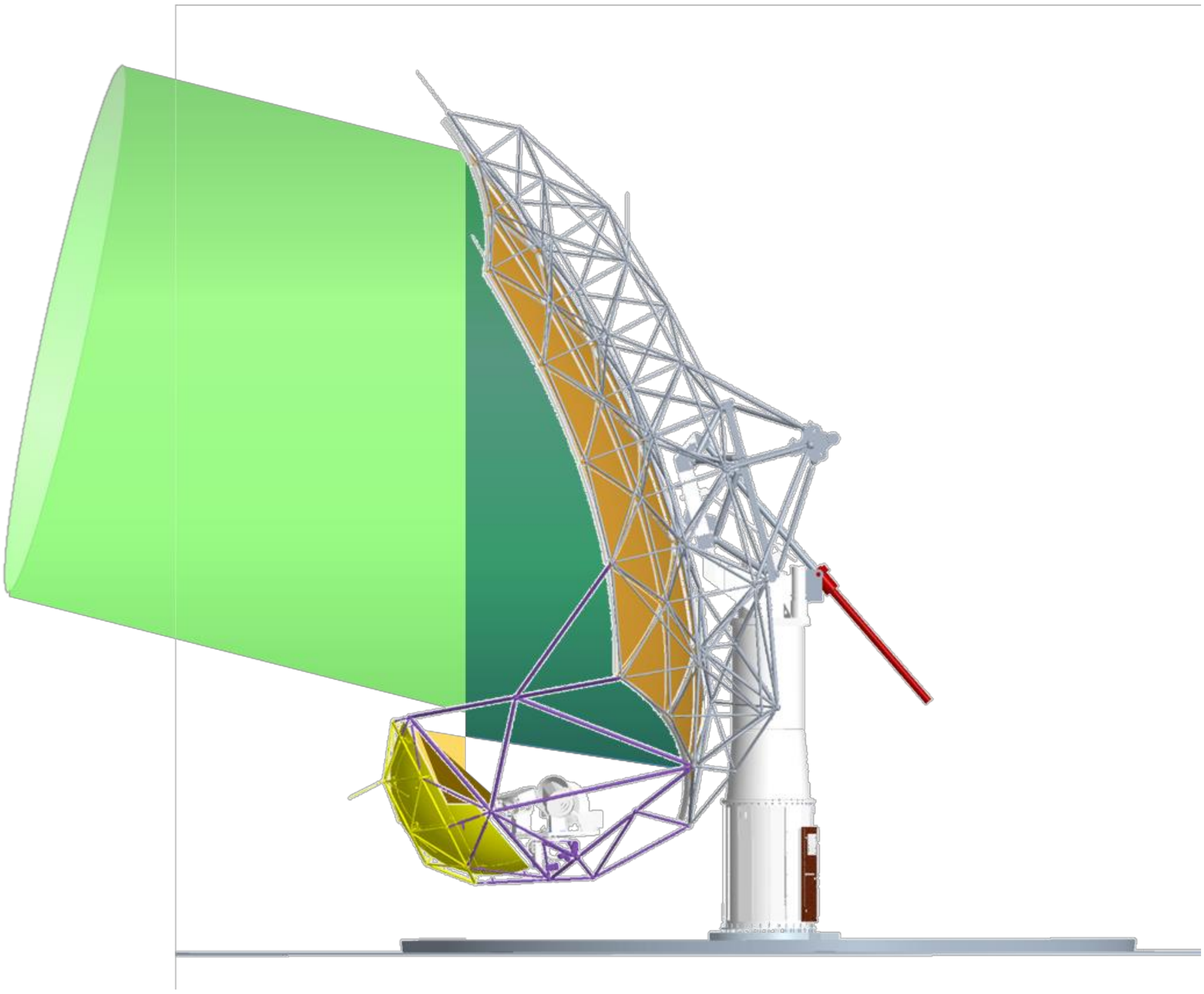


Figure 46: Optical Path Geometry

3.2.4.2 Main Reflector

The main reflector consists of panels, backup structure and adjusters. The 66 pieces of panel form the reflector surface and each panel can be aligned by the adjusters. The backup structure adopts the space frame with bolted ball knots and tubes.

Each panel adopts aluminium skin reinforced with slot ribs. The conductivity of the aluminium is 34.5 x10^6 Siemens/m, better than the requirement of 4x10^6 Siemens/m.

The main reflector surface layout is shown in Figure 47.

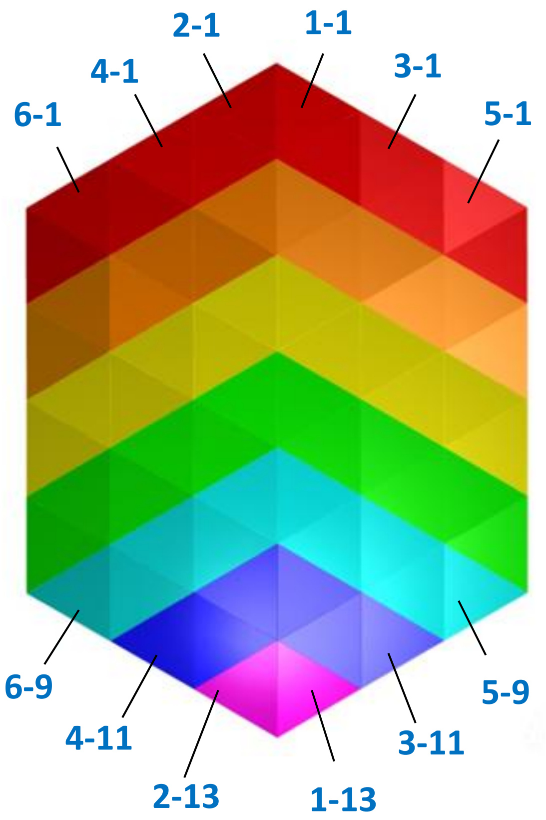


Figure 47: Geometry of Main Reflector Panels

Table 4: Area of the Half Panels for the Main Reflector

No.	Area (m^2)	No.	Area (m^2)	No.	Area (m^2)
1-1	3.765	1-12	3.850	3-10	3.910
1-2	3.774	1-13	4.165	3-11	4.063
1-3	3.691	3-1	3.785	5-1	3.895
1-4	3.696	3-2	3.804	5-2	3.939
1-5	3.637	3-3	3.725	5-3	3.869
1-6	3.640	3-4	3.744	5-4	3.925
1-7	3.601	3-5	3.692	5-5	3.889
1-8	3.608	3-6	3.715	5-6	3.974
1-9	3.624	3-7	3.696	5-7	3.999
1-10	3.645	3-8	3.740	5-8	4.163
1-11	3.762	3-9	3.797	5-9	4.246

min. (m^2)	3.601	max. (m^2)	4.246

In order to minimise the energy leakage through the gaps of the main reflector and avoid the impact between panels with thermal expansion, fabrication & installation tolerances, deflections under load, the 3mm panel gap width is determined.

The panel structure is processed by topological optimization, as shown in Figure 48, which shows the possible distribution of ribs in red part.

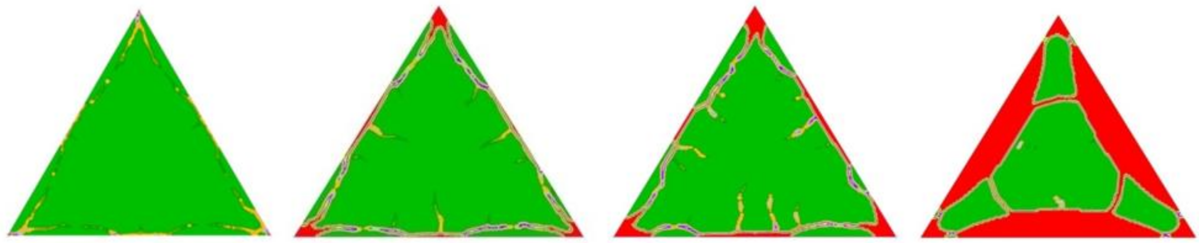


Figure 48: Rib Layout by Topological Optimization

Considering the manufacture process, two possible rib layouts are shown in Figure 49.

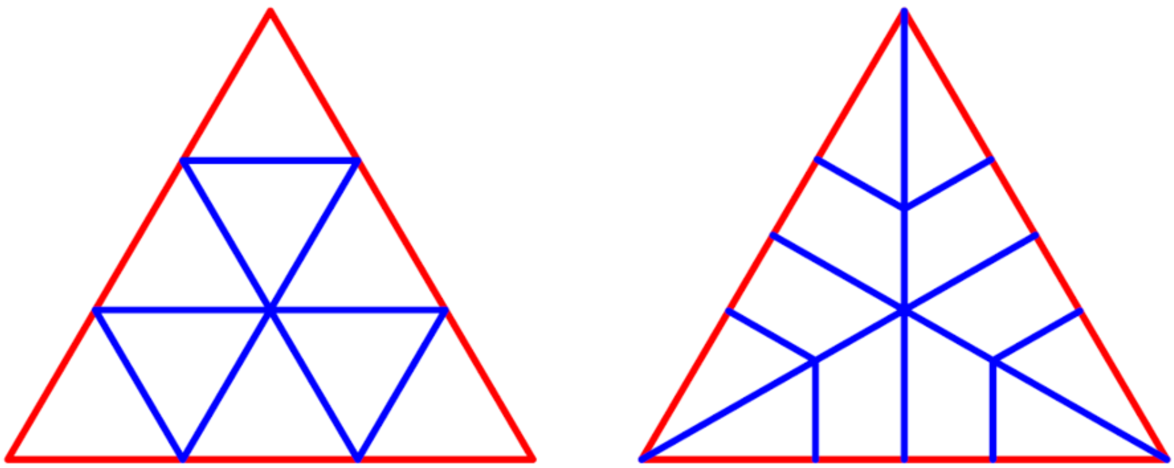


Figure 49: *left:* Triangle Distribution Ribs / *right:* Fishbone Distribution Ribs

The FEA results are shown in Figure 50 and Figure 51, from which the fishbone layout structure has lower deformation and is adapted.

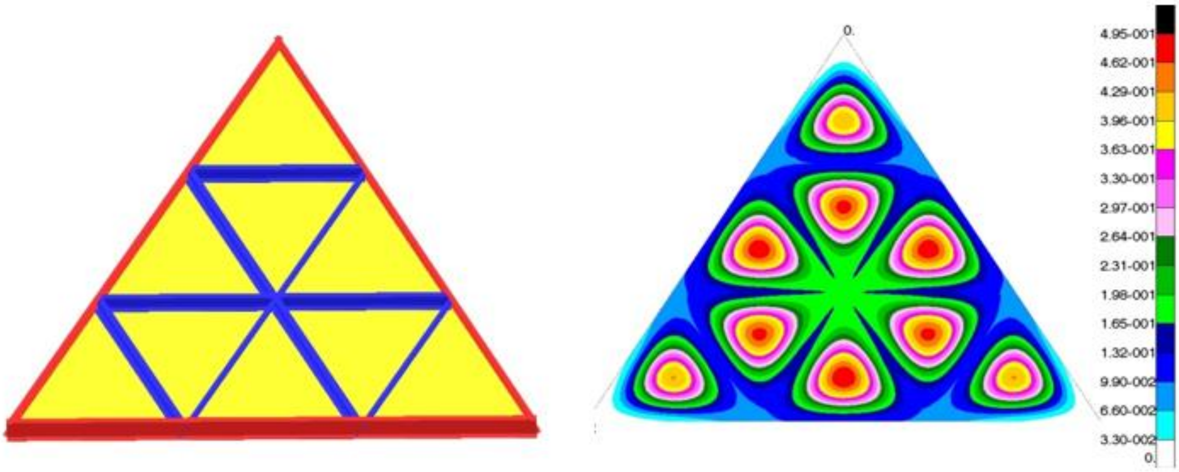


Figure 50: Triangle Rib Layout and Deformation

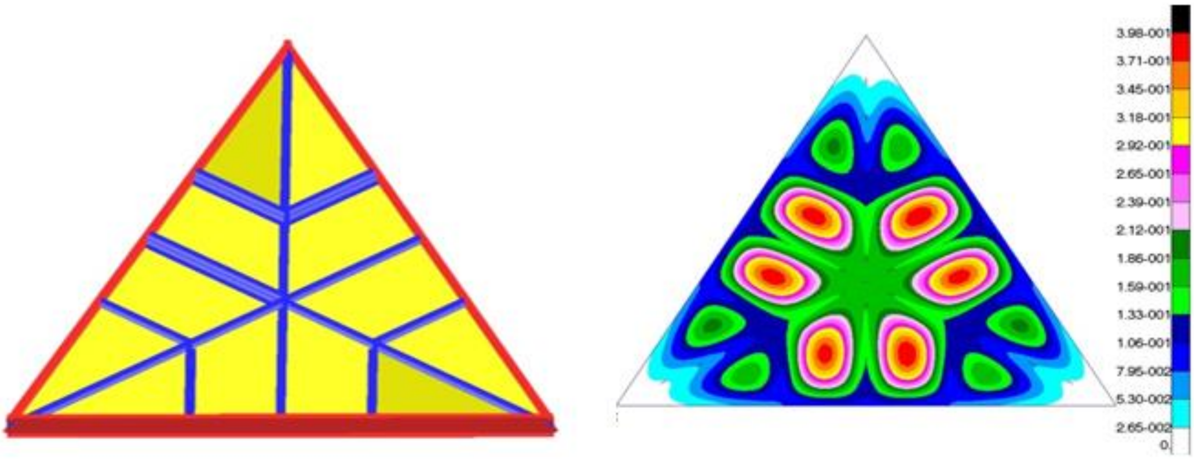


Figure 51: Fishbone Rib Layout and Deformation

The panel skin thickness is 1.5 mm and the Z-shaped rib is also optimized as well as the rib interval.

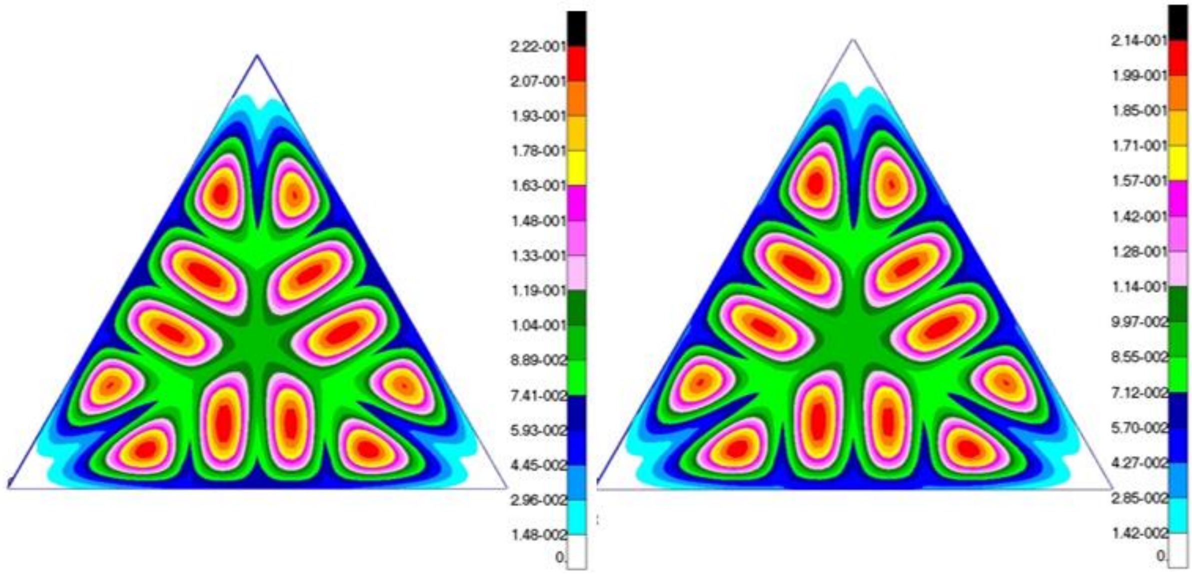


Figure 52: Optimization on Ribs

The final optimized panel structure is shown in Figure 53. The panel accuracy under gravity load is 0.065 mm (rms), which meets the design requirement. There are two kinds of Z-shaped ribs of 150mm and 100mm in height. The interval between ribs are from 300mm to 350mm. The panel is supported at each corners, as shown in Figure 53.

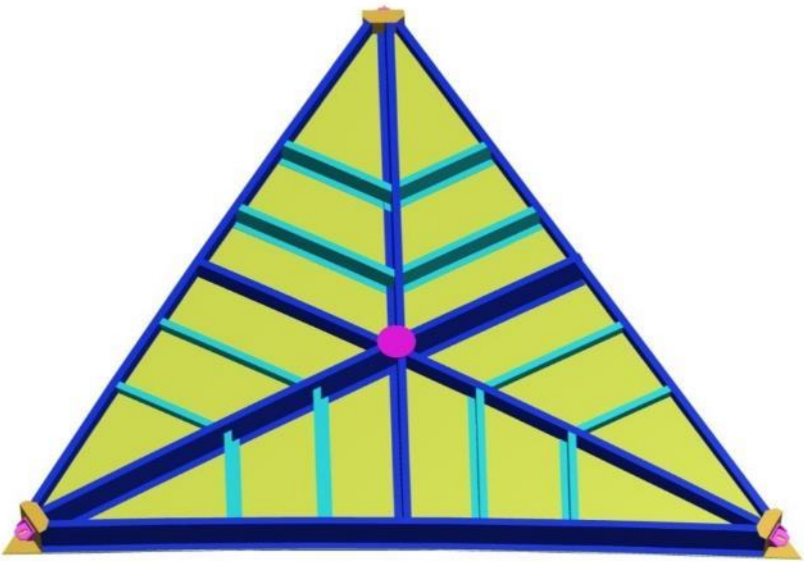


Figure 53: Final Panel Structure

The panel is fabricated by using the vacuum negative pressure method, as shown in Figure 54.

Figure 54: Panel Fabrication

CETC54 has manufactured many panel prototypes for experiment based on this design, the surface accuracy is better than 0.1mm R.M.S., one of which is shown in Figure 55.

Figure 55: Single Panel Photograph

3.2.4.3 Adjuster

3.2.4.3.1 Length Optimization

The adjuster is used for connecting the panel and BUS, which has following functions:

- panel supporting:
  when the antenna is travelling in EL, the adjuster is used to support the panel in order to keep reflector error.
- panel adjustment:
  by using the adjuster to realize the high accuracy surface at the beginning of installation
- deformation coordination:
  when the panel is in different material with backup structure, adjuster could be used for fitting the deformation between the panel and the backup structure;
  therefore, the adjuster should be processed optimization design

When the antenna is in different elevation and thermal load, the diameter and length of the adjuster are optimized to fulfil the pre-set parameters. Some optimization results are shown in Figure 56 and Figure 57.

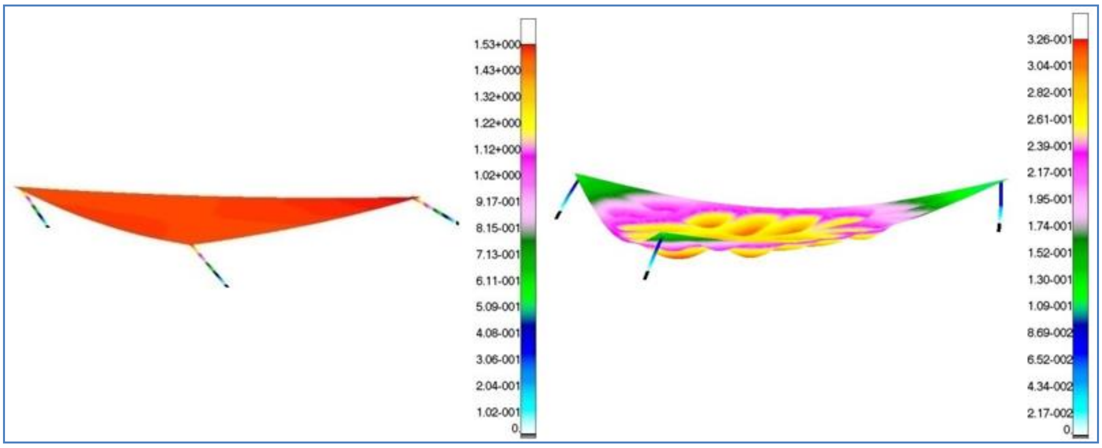


Figure 56: Single Panel Deformation under Gravity Load

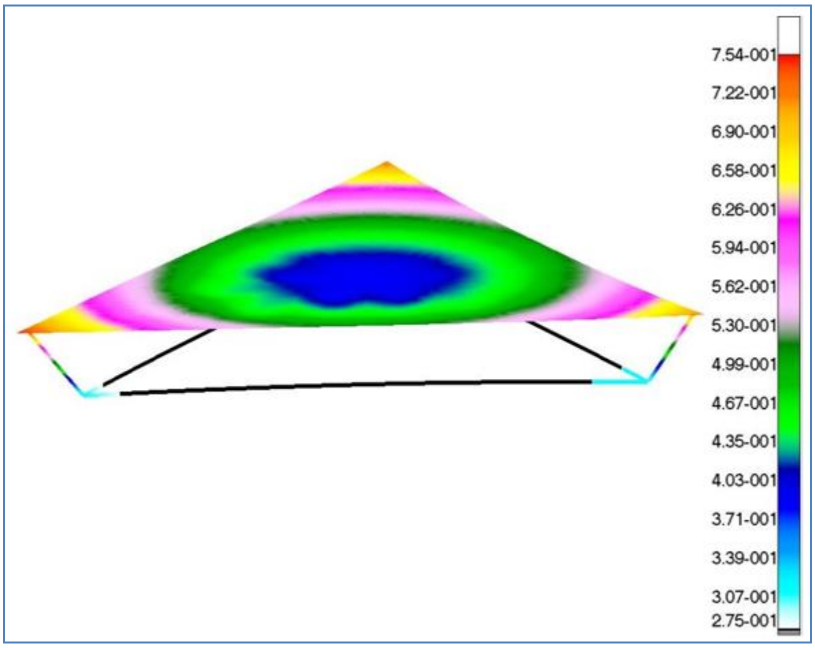


Figure 57: Single Panel Thermal Deformation with Temperature Difference 50° C

3.2.4.3.2 Detail Design

The adjuster consists of stud, nuts, conical washers, and spherical washer. Layout of adjuster and panel is shown in Figure 58.

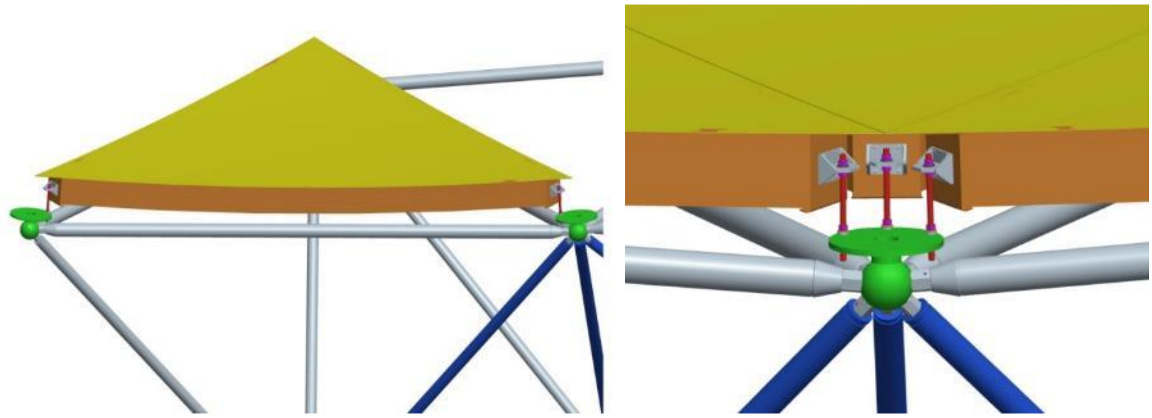


Figure 58: Layout of Adjuster and Panel

Adjustments will be done from the backside by adjusting the nuts, as shown in Figure 59.

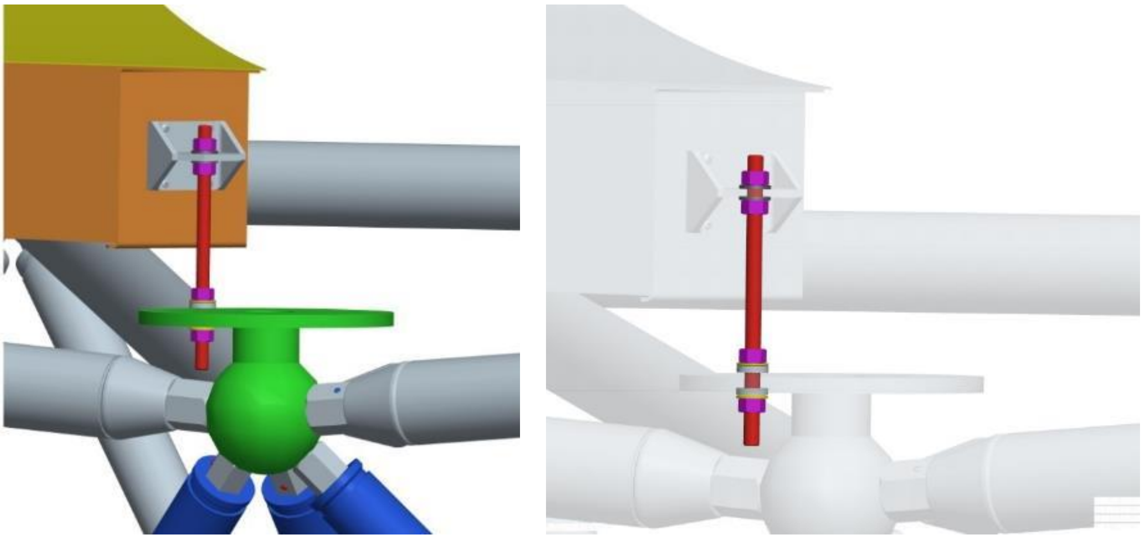


Figure 59: Adjuster Distribution and Structure Diagram

The dimension of the adjuster is shown in Figure 60

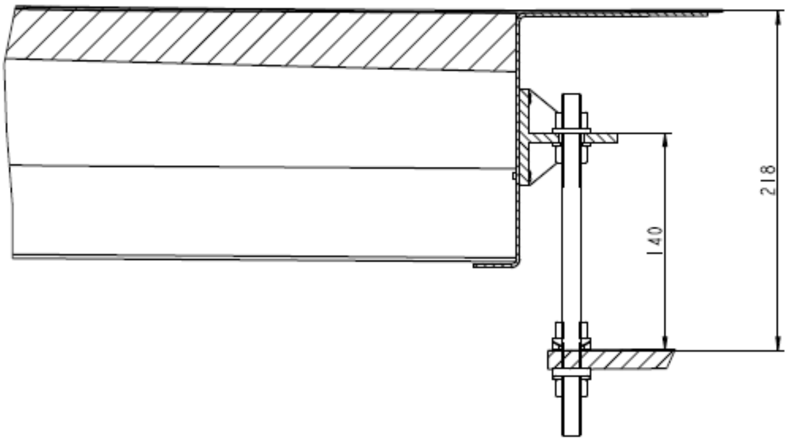


Figure 60: Adjuster Structure Diagram

3.2.4.4 BUS

3.2.4.4.1 Space Frame Backup Structure

The backup structure adopts tetrahedron space frame design. Single and group tetrahedron units of the backup structure are shown in Figure 61 and Figure 62.

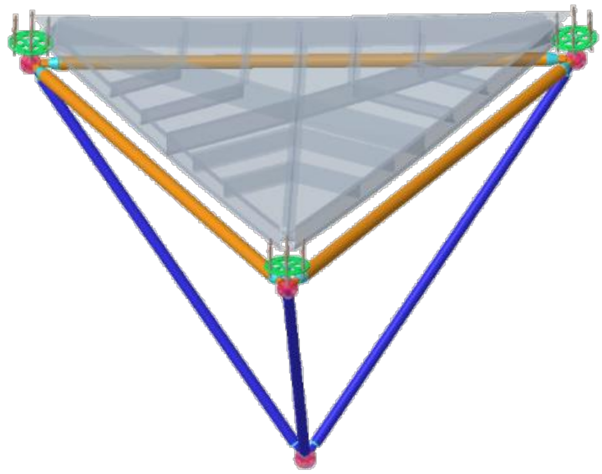


Figure 61: Single Tetrahedron Unit Diagram

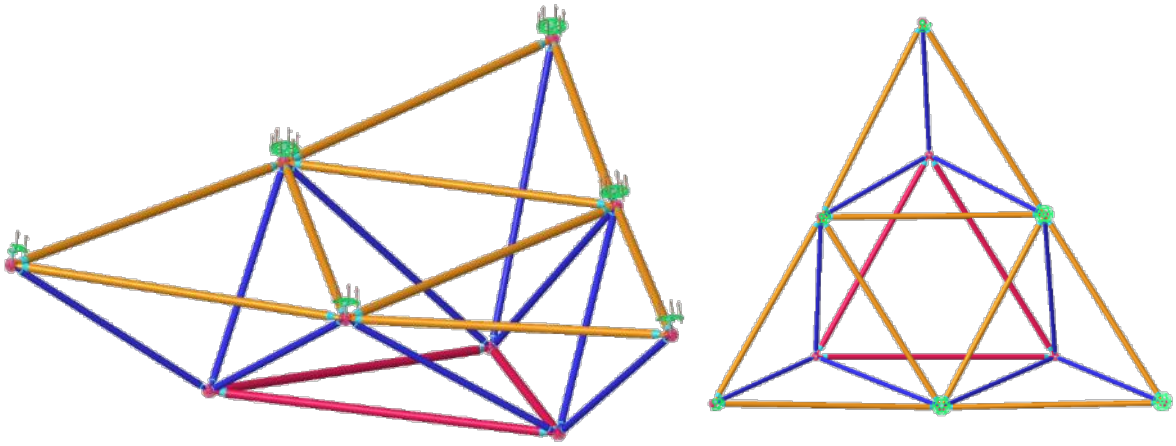


Figure 62: Group Tetrahedron Unit Diagram

All of tubes are connected by bolted knot. The design of knots and bolts are popular standard components. The backup structure design is shown in Figure 63, Figure 64 and Figure 65.

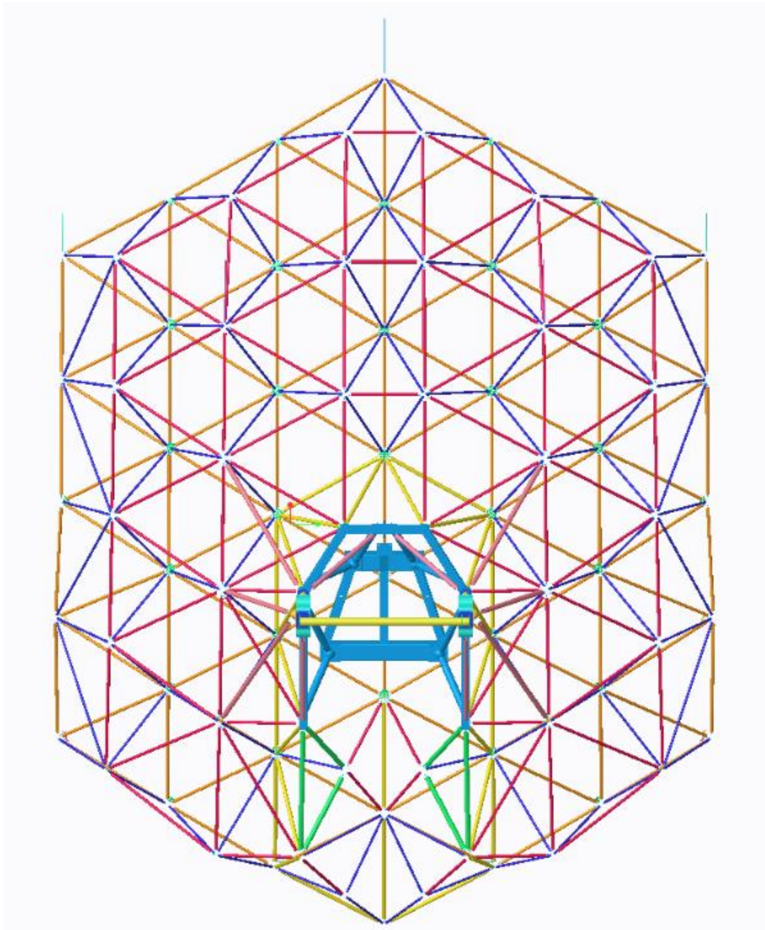


Figure 63: Backup Structure Diagram (1)

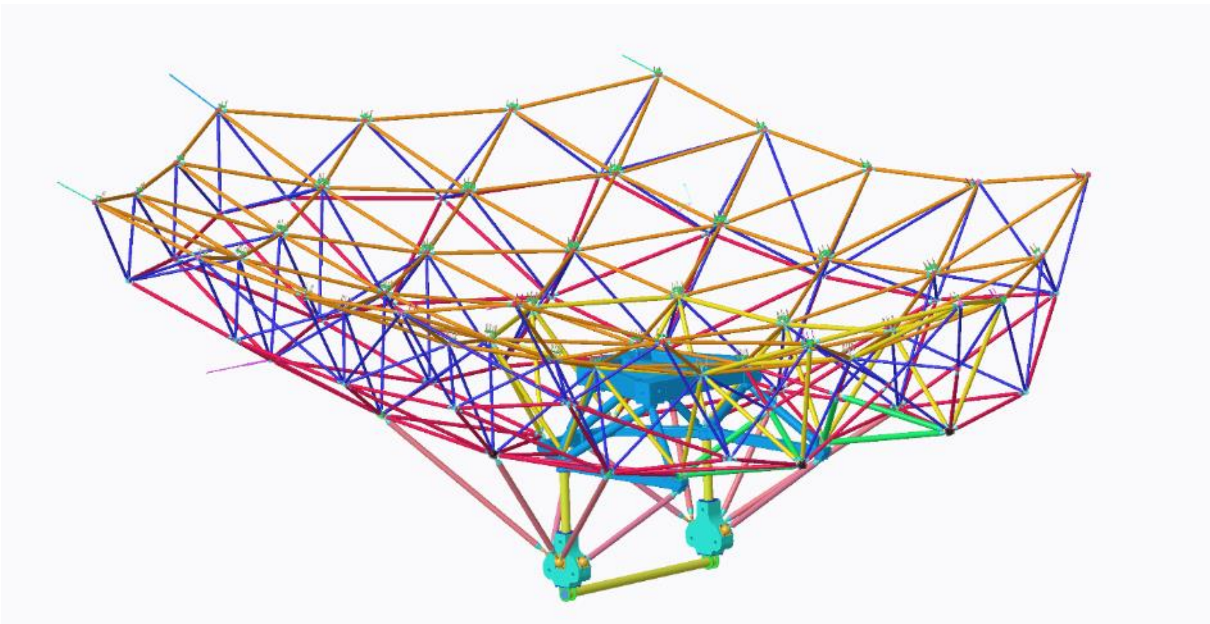


Figure 64: Backup Structure Diagram (2)

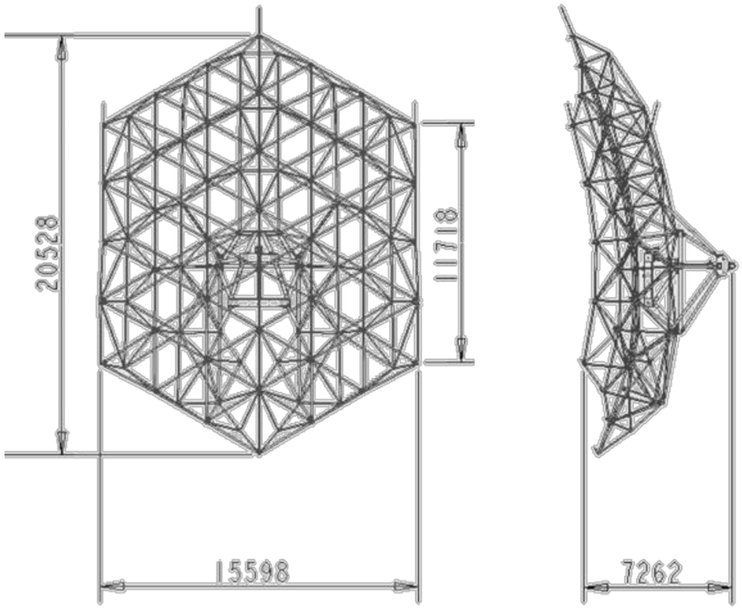


Figure 65: Backup Structure 2D Drawing

3.2.4.4.2 Detail Design

The backup structure is consisted of four types of tubes with different diameters and thicknesses:

Ø60mm×3mm, Ø76mm×3mm, Ø95mm×5mm and Ø121mm×5mm. Correspondingly, dimensions of the screws (diameter × length) at the ends of tubes are 20mm×22mm, 24mm×26mm, 27mm×30mm and 30mm×33mm, as shown in Figure 66 to Figure 70.

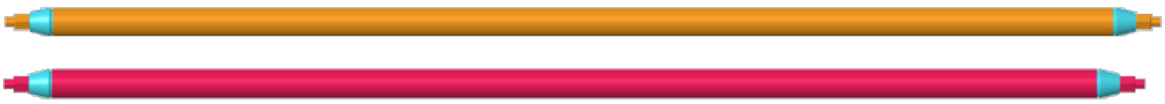


Figure 66: Diagrams of the Upper and Lower Chord Tubes (Ø76mm×3mm)

Figure 67: Diagram of the Interlayer Tube (Ø60mm×3mm)

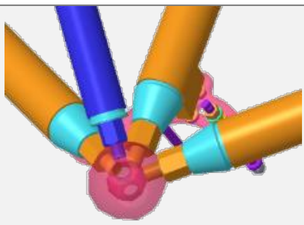
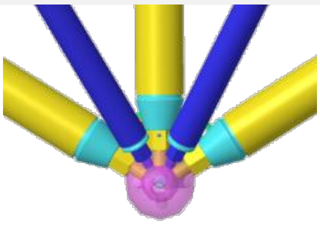
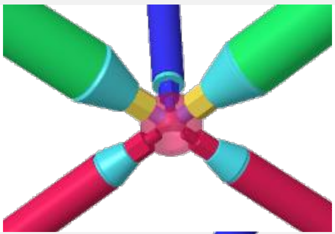
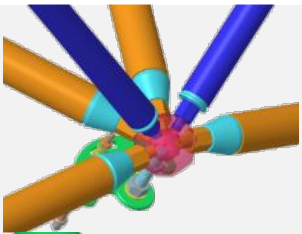
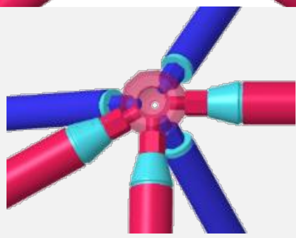
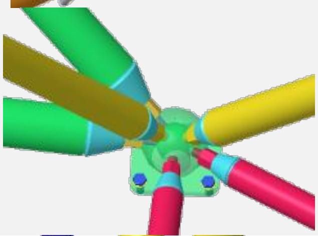
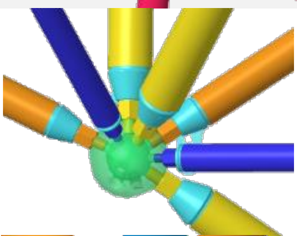
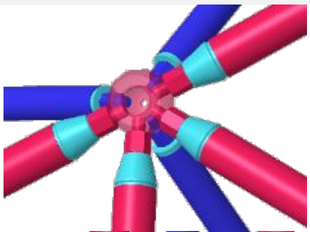
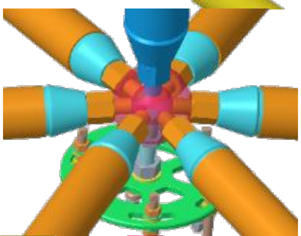
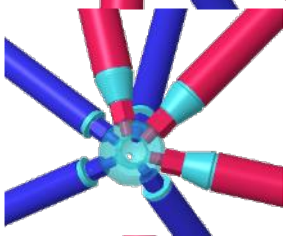
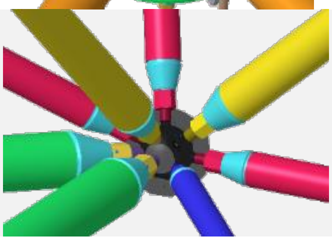
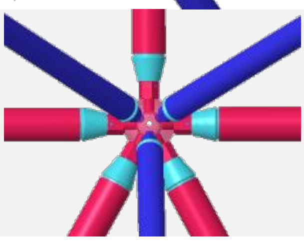
Figure 68: Diagram of the Reinforced Chord Tube (Ø95mm×5mm, around the Reflector Support)

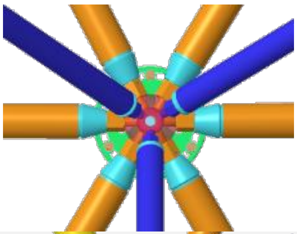
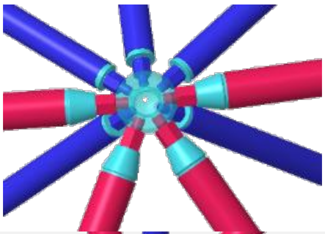
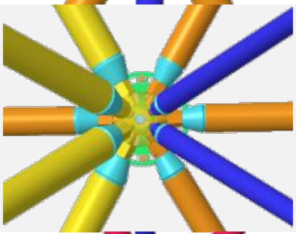
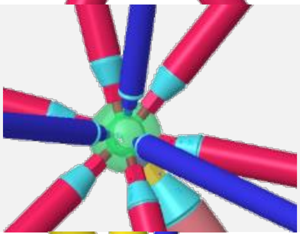
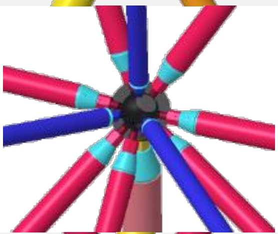
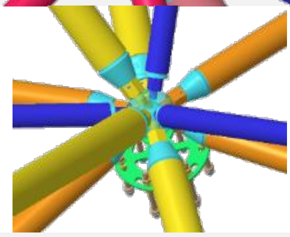
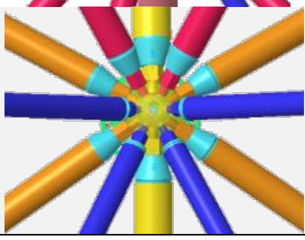
Figure 69: Diagrams of the Lower Tube Connected with the Reflector Support (Ø121mm×5mm)

Figure 70 Diagrams of the Tube Connected with the Counterweight (Ø121mm×5mm. Lengths of screw at both ends are different: the longer one is 137mm and the shorter one is 33mm which is same as the “green” tube in Figure 69.)

There are 9 different typers of knots, each connected with 4 to 12 tubes, as shown in Table 5.

Table 5 Knots Structure Diagram

Number of tubes	Type of the knot	
4		
5		
6		
		
7		
		
8		

9		
10		
11		
12		

The exploded view and 2D drawing of bolt connection are shown in Figure 71 and Figure 72. The knots design meets Chinese standard, as shown in Figure 73.

Figure 71: Exploded View of Bolt Connection

The o-rings on the nuts are used to prevent water entry into the tubes.

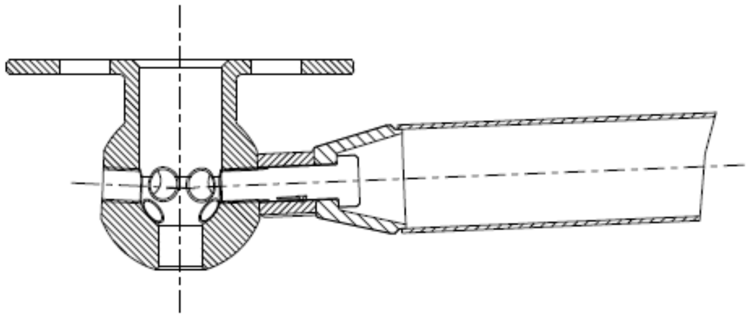
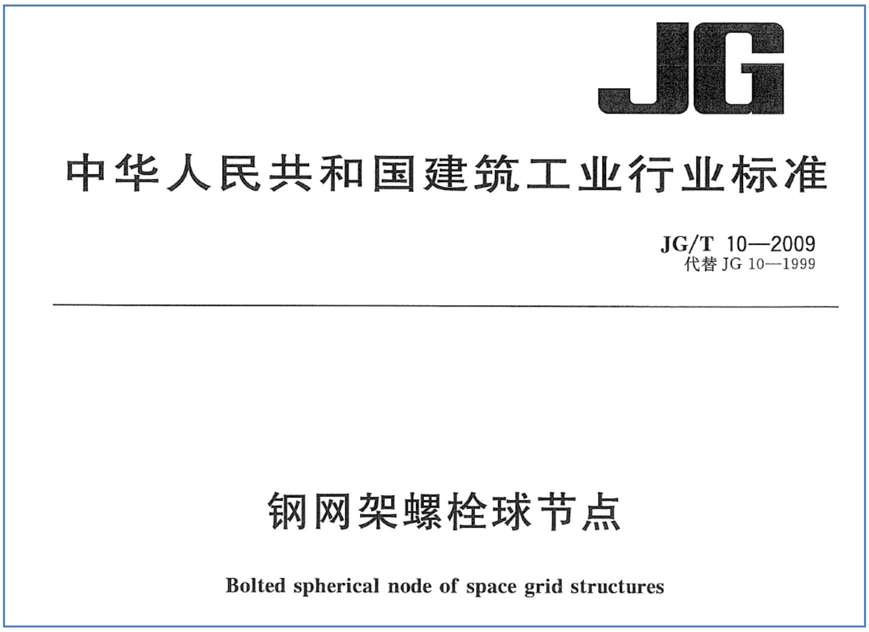


Figure 72: 2D Drawing of Bolt Connection



JG

中华人民共和国建筑工业行业标准

JG/T 10—2009
代替 JG 10—1999

钢网架螺栓球节点

Bolted spherical node of space grid structures

Figure 73: Chinese Standard of Bolted Knots

3.2.4.5 Elevation Turnhead Frame

3.2.4.5.1 Elevation Turnhead Frame

The elevation turnhead frame is used to connect backup structure and turnhead, which consists of rectangular pipes, knots and hinge joints, as shown in Figure 74.

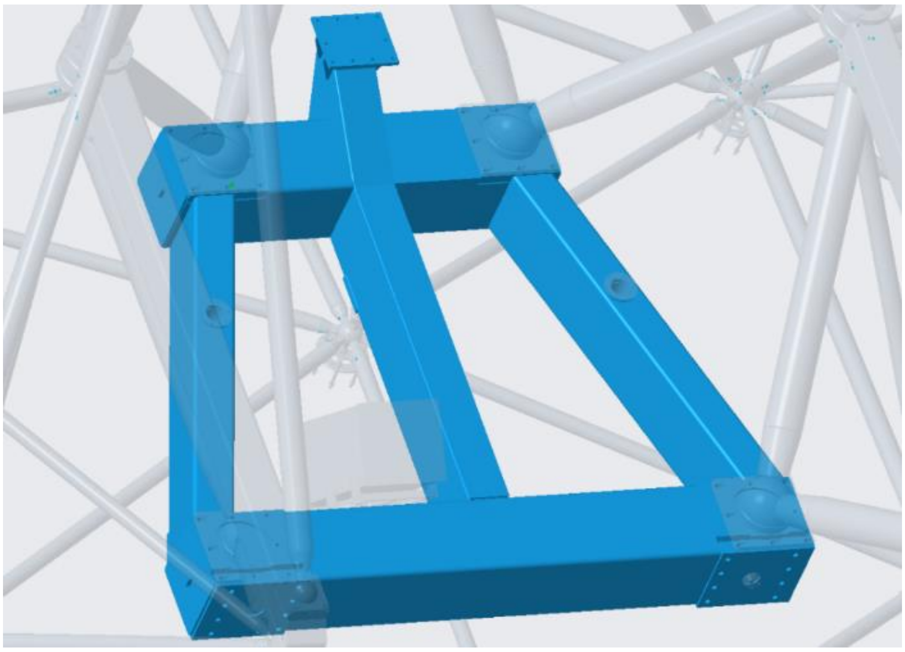


Figure 74: Elevation-Turnhead Frame Location Relationship Diagram

The frame is welded by steel rectangular tubes with the type of 400 mm, 10 mm in the wall thickness. After welding, the mounting interfaces with photogrammetry reference targets are accurately machined for use during the reflector alignment process. The dimension of elevation-turnhead frame is shown in Figure 75.

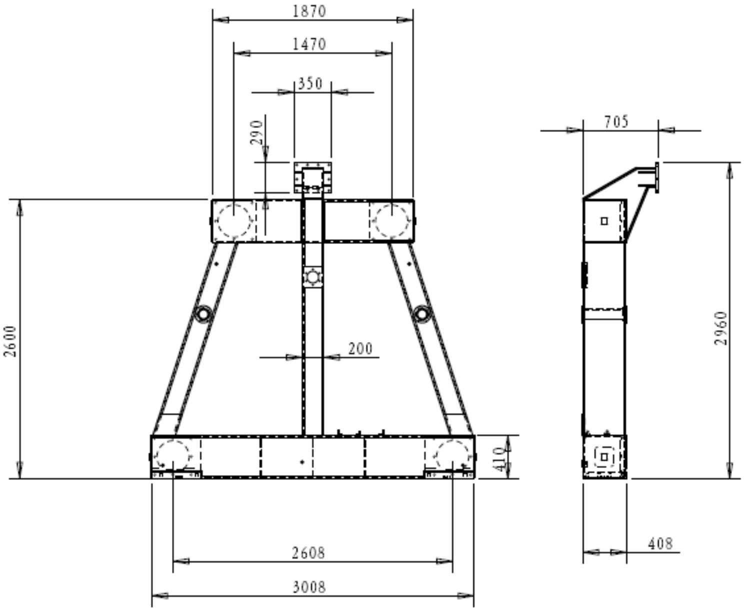


Figure 75: Elevation-Turnhead Frame 2D Drawing

The frame is first connected to a gantry by four V-shaped frames (two tubes, Ø180mm×6mm), then mounted on the backup structure, as shown in Figure 76. Meanwhile, it is connected with the turnhead and ball jackscrew by five hinge joints, as shown in Figure 76 and Figure 77.

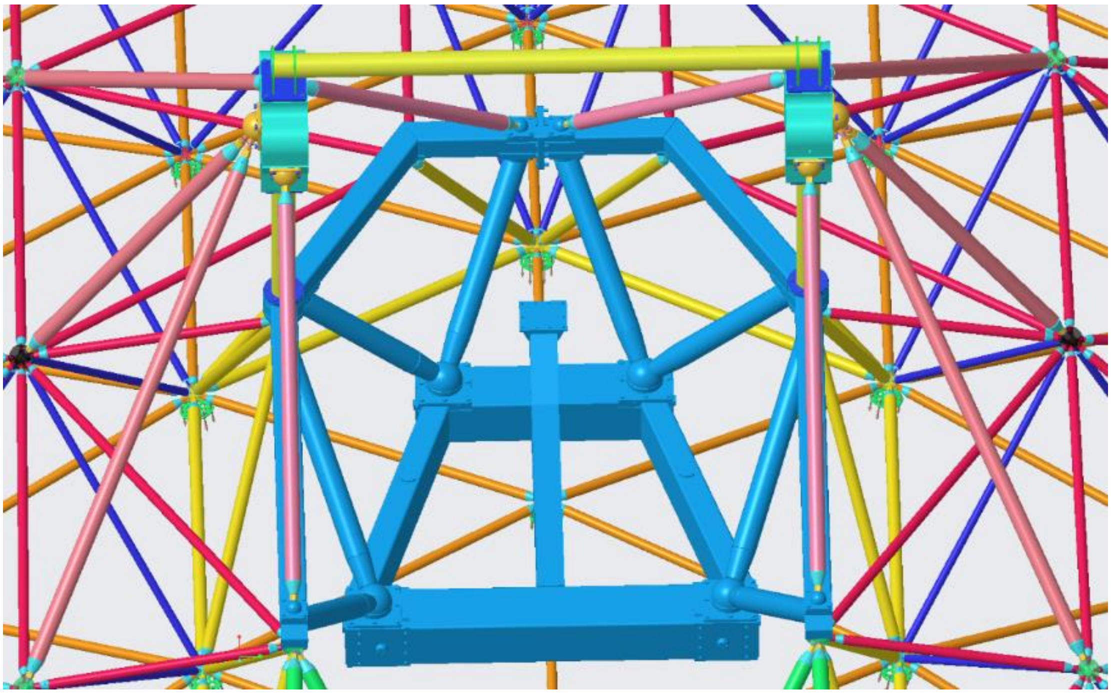


Figure 76: Connection between the Elevation-Turnhead Frame and the Backup Structure

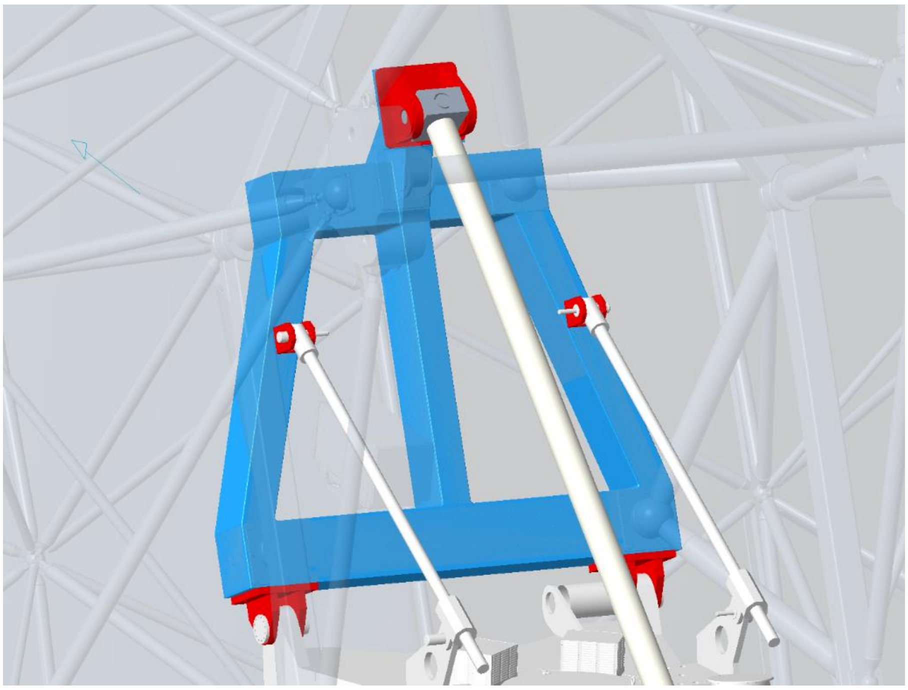


Figure 77: Connection between the Elevation-Turnhead Frame and the Turnhead and Ball Jackscrew

3.2.4.5.2 Knot Design

The Elevation-Turnhead Frame knots are hemisphere with the diameter of 270mm and welded with the frame.

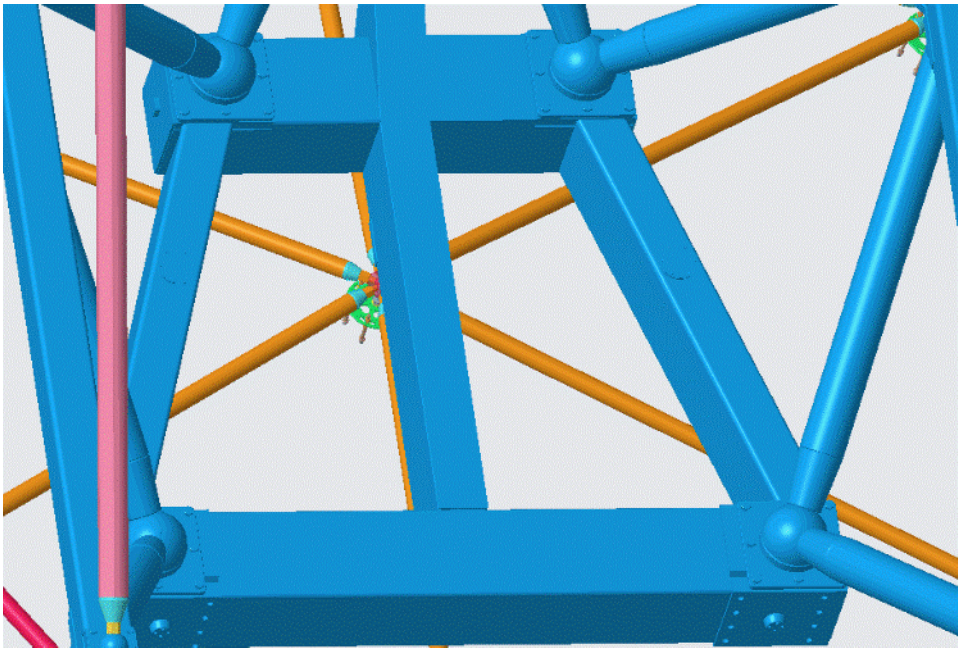


Figure 78: Elevation-Turnhead Frame Knots Structure Diagram

3.2.4.6 Subreflector

The subreflector adopts CFRP BUS and CFRP panels. The reflecting surfaces of the panels are metalized with aluminium by the surface metallization technique. The thickness of the metallic layer is more than 140 um. The conductivity of the metallic skin is about 5x10^6 Siemens/m, better than 4x10^6 Siemens/m.

3.2.4.6.1 Subreflector Design

The subreflector adopts Carbon Fiber Reinforced Polymer (CFRP) material. CFRP has not only high specific modulus but also low CTE, which is very suitable for SKA project. The surface metallization technique is used for improving CFRP reflector reflecting performance. The subreflector dimension is about 4.5m, mainly including panel, BUS, adjusters, and extension etc., as shown in Figure 79.

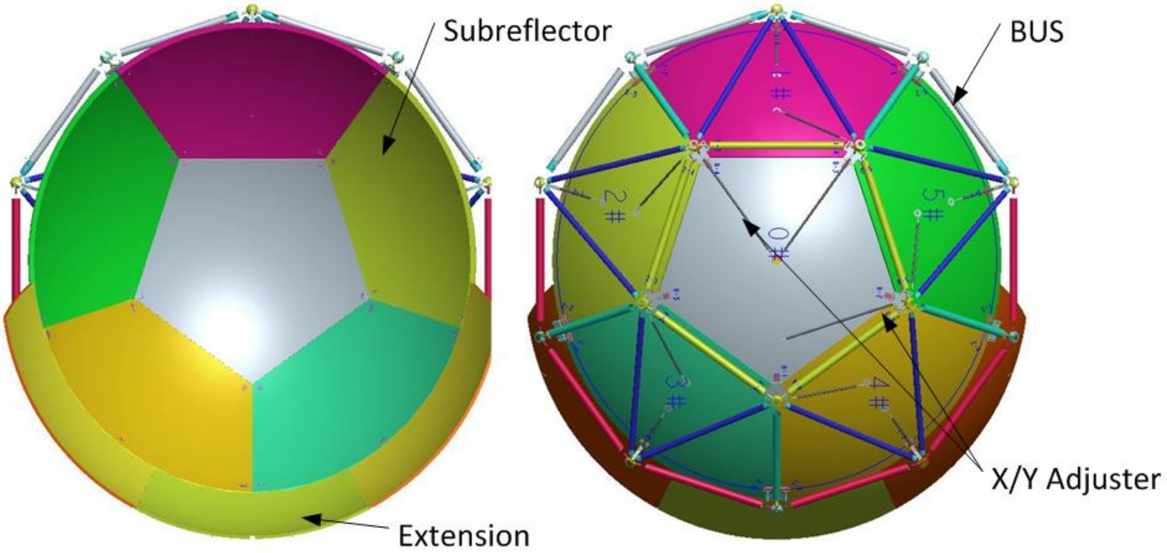


Figure 79: Subreflector Structure: Front and Back View

3.2.4.6.2 Panel Design

The subreflector is divided into six CFRP sandwich panels, one panel in the middle, and the other five panels in the outer ring, as shown in Figure 80.
In order to minimise the energy leakage through the gaps of the subreflector and avoid the impact between panels with thermal expansion, fabrication & installation tolerances, deflections under load, the 1mm panel gap width is selected.
Its advantages are:

- easy to manufacture the mould and realise the high accuracy
- easy to manufacture the panel and realise the high accuracy
- easy for shipping and road transportation

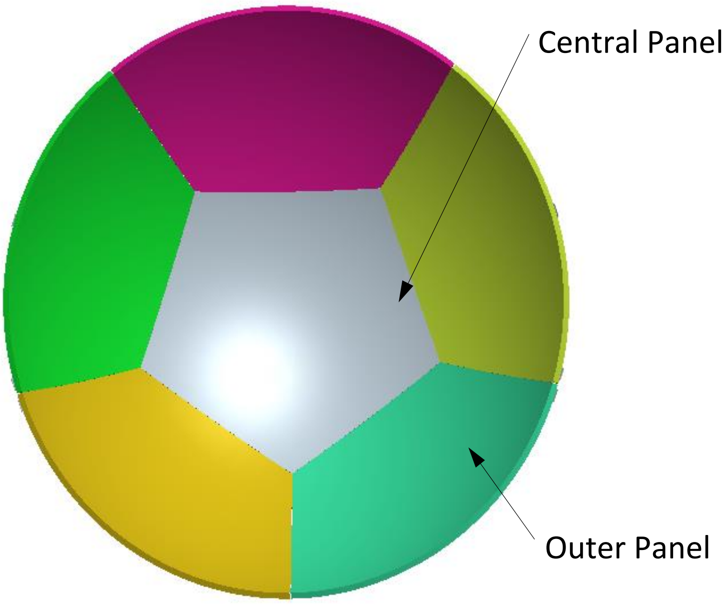


Figure 80: Subreflector Panels: Front View

Each panel adopts carbon fiber skin and aluminium honeycomb sandwich structure, manufactured on the mould in autoclave with vacuum negative pressure method. The surface accuracy can achieve 0.08 mm (rms) for each panel, and 0.2 mm (rms) for the whole subreflector. The metal spraying on the mould is shown in Figure 81.

Figure 81: Metal Spraying Robot

Considering the fabrication technology, there are three metal coating designs, Side coated (SC), Reflecting Surface Expended & Side coated (RSE&SC), and Side uncoated (SU), as shown in Figure 82. By the full-wave simulations (referring to Section 3.4.3.2), the RSE&SC design is selected for metal coating, and aluminium layer thickness is 140um.

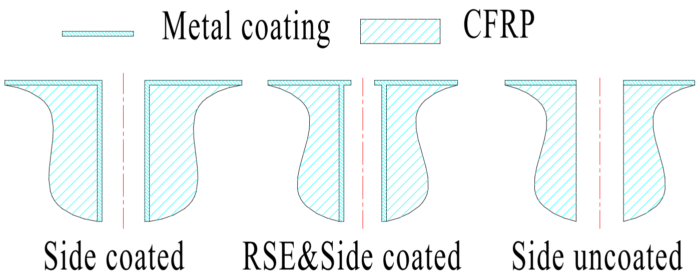
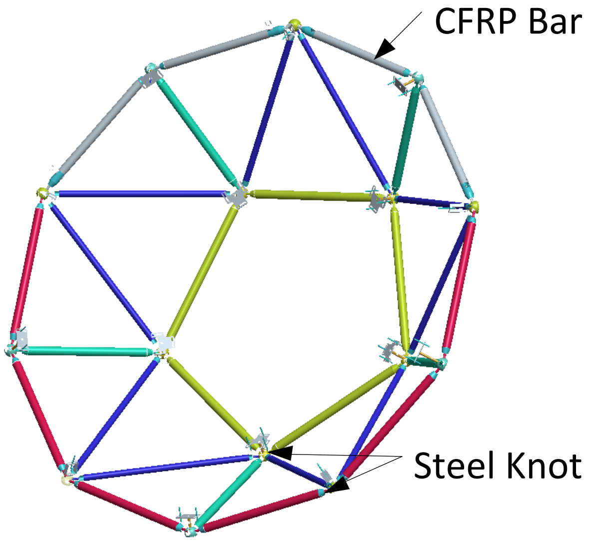


Figure 82 Sub-reflector panel model with three types of metal coating.

3.2.4.6.3 Subreflector BUS

Same as the BUS of the main reflector ,the subreflector BUS adopts space frame structure connected with steel knots and carbon fiber tubes. All of tubes are connected by bolted knots. The surface accuracy and position of the subreflector can be adjusted by adjusters. The subreflector BUS is



shown in
Figure 83.

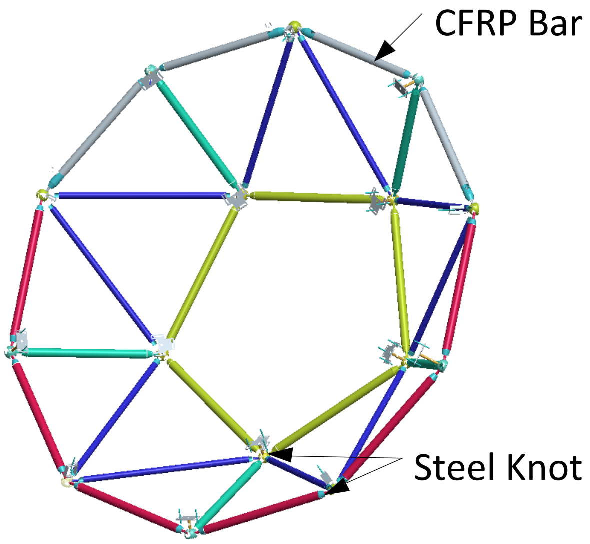


Figure 83: BUS of the Subreflector

Each tube adopt a carbon fiber pipe with two steel connectors. The carbon fiber pipe is connected with steel connector by gluing method. The steel connectors are manufactured with spiral slots to enhance the connecting strength, as shown in Figure 84.

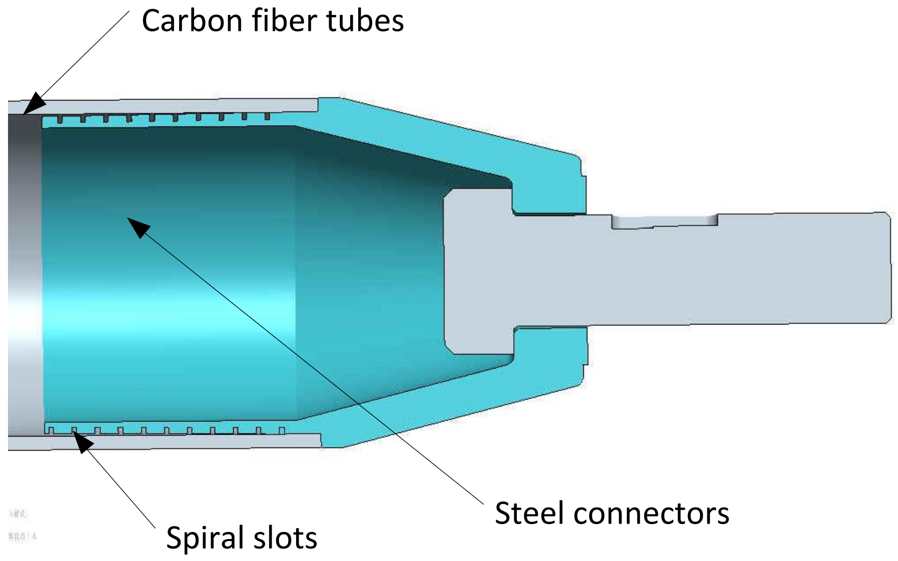


Figure 84:Connection between carbon fiber tubes and ends

3.2.4.6.4 Adjuster

There are two kinds of adjusters: one is mainly to adjust the surface precise accuracy of panels(to adjust panels in Z direction, so named as Z adjuster), and the other is to adjust the X/Y position (to adjust panels in X/Y direction, so named as XY adjuster) .The layout of precise adjuster between BUS and sub-reflector panel is shown in Figure 85. The detail of the adjuster is in Figure 86.

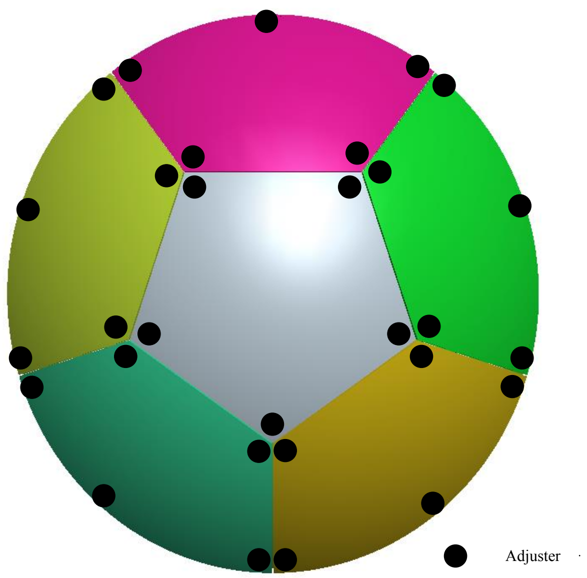


Figure 85: Layout Of Surface Precise Adjuster

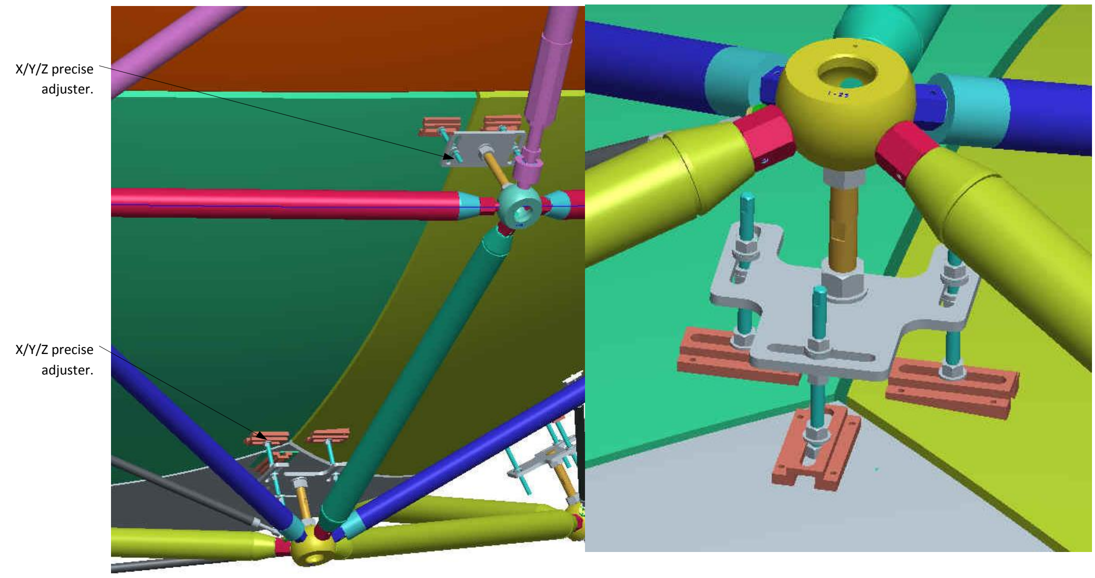


Figure 86: Surface Precise Accuracy Adjuster

The XY adjusters are shown in

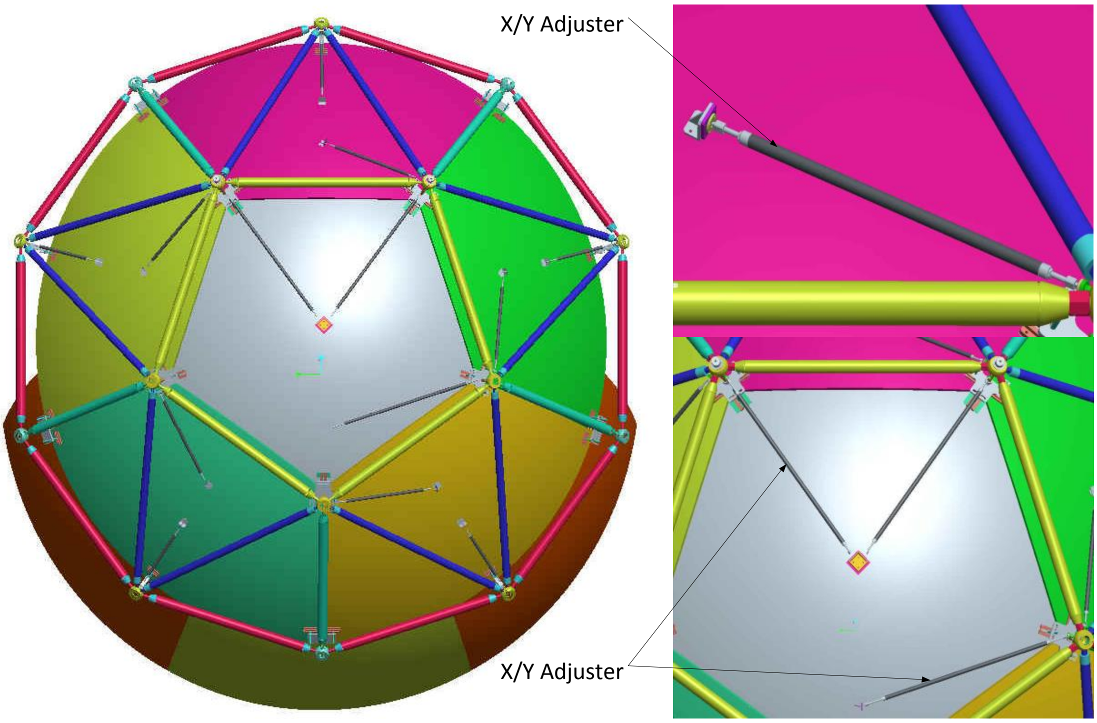


Figure 87. Ball joints are designed at both ends of the adjuster rod for X/Y position adjustment. The slots on the BUS and panels are used for adjusting the position of panels in the X/Y directions.

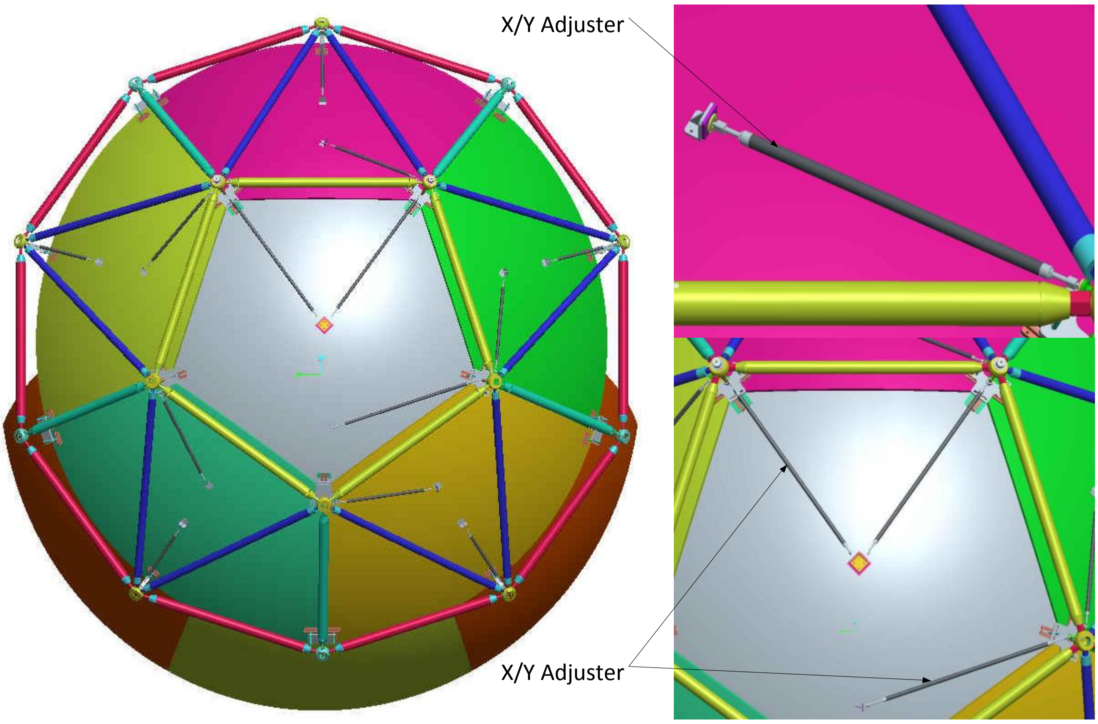


Figure 87: XY adjuster

3.2.4.6.5 Extension

The extension is applied at subreflector lower edge for reducing noise temperature caused by feed spillover, as shown in

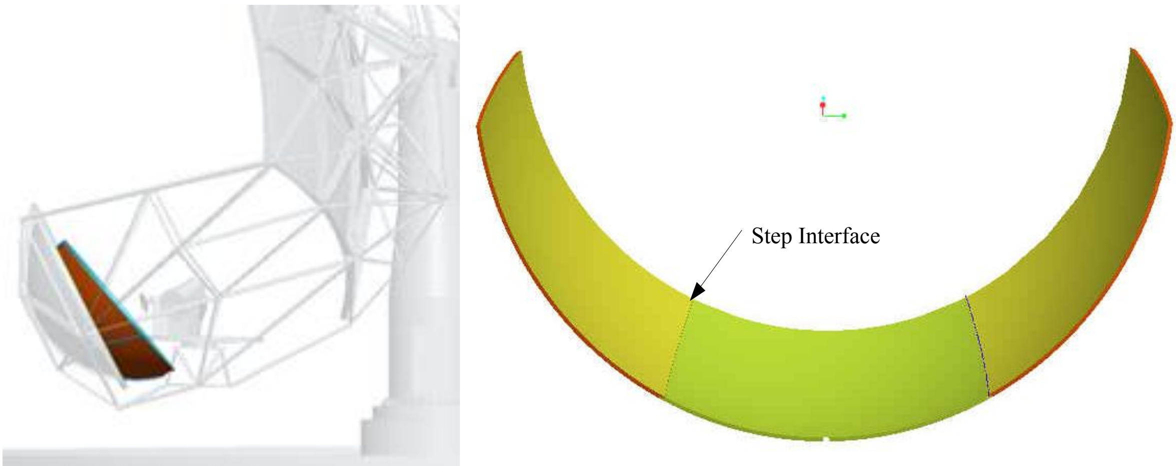


Figure 88. The sub-reflector extension also adpots sandwich structure. However the skins of extensions are made of glass fiber and the core material is foam. The extension consists of three pieces. The central piece of extension is overlapped with adjacent pieces using step interface. The

three pieces are bolted as a single extension using the embedded bolts, as shown in

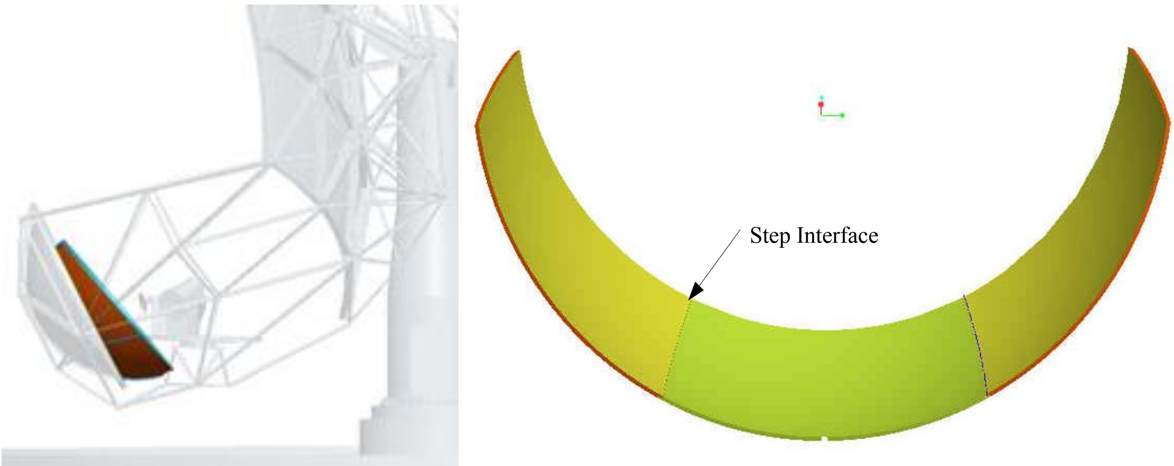


Figure 88. Meanwhile, the extension is overlapped with sub-reflector using inclined interface and supported by support arm, as shown in Figure 89.

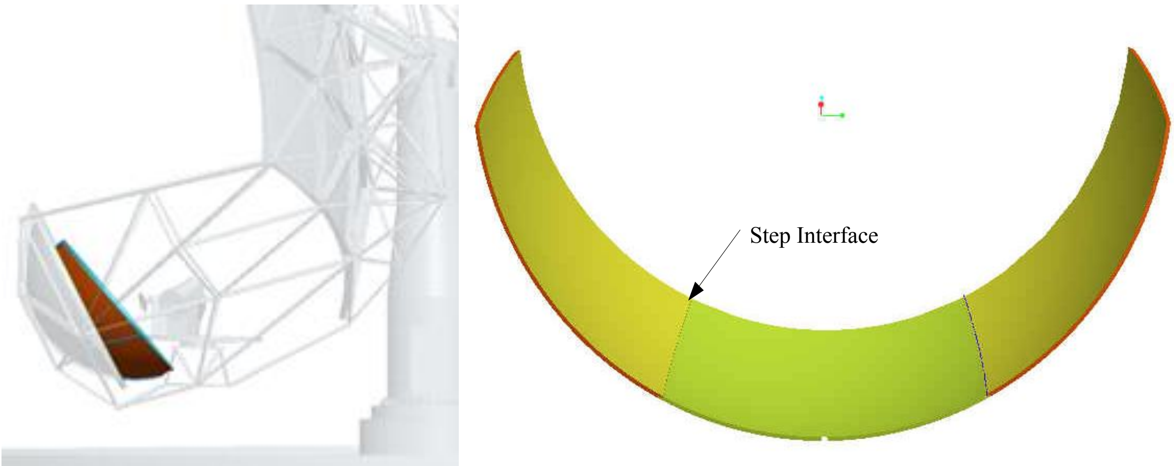


Figure 88: Extension Structure

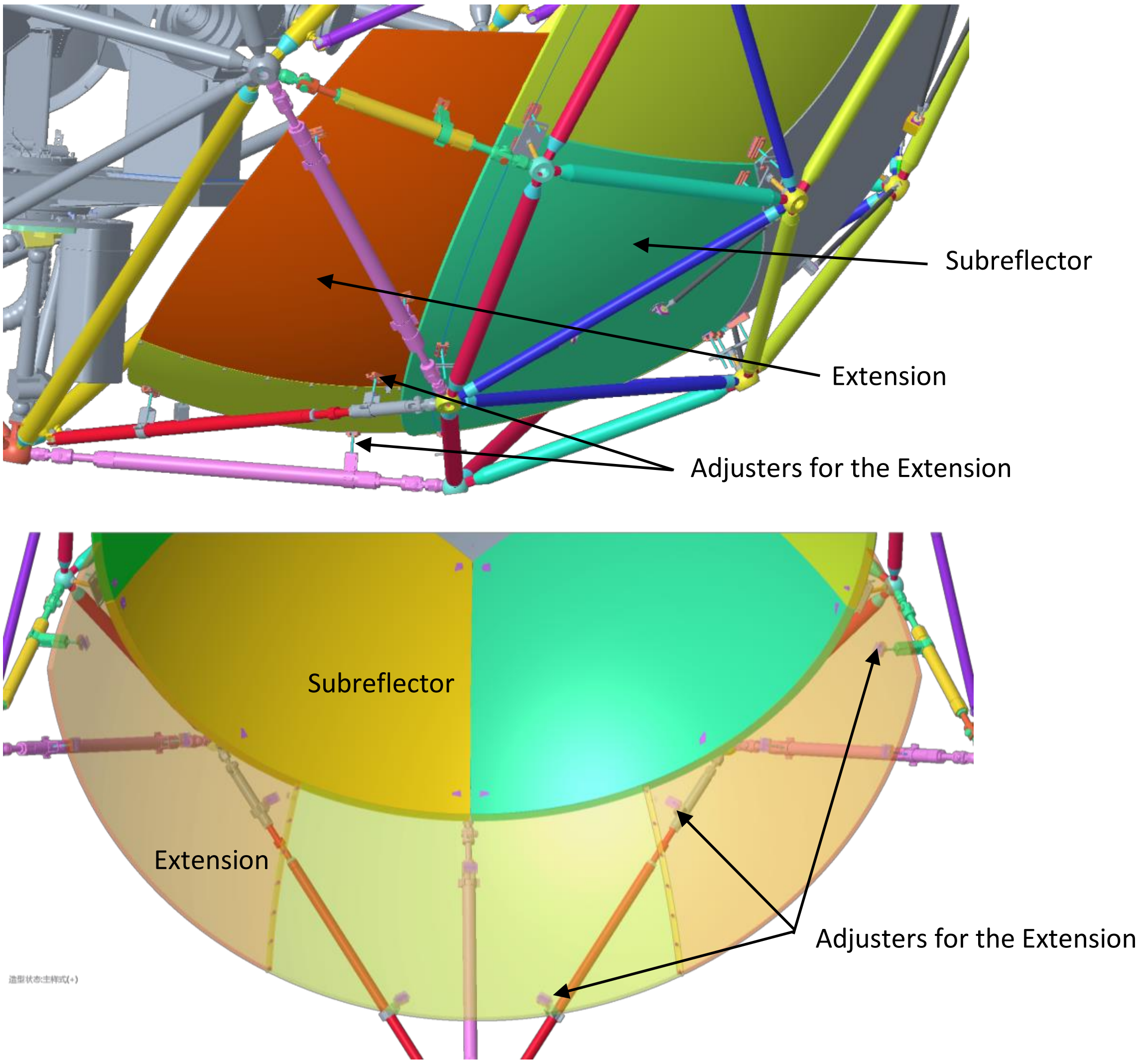


Figure 89: Connection between sub-reflector and its extension

3.2.4.7 Support Arm

3.2.4.7.1 Support Arm Design

The arm is a truss frame that connects the main reflector and the subreflector. It also supports the feed and the indexer. The truss frame consists of steel tubes and knots.
The diameters and thicknesses of the tubes are Ø95mm×4mm, Ø76mm×3mm. The arm structure is shown in Figure 90.

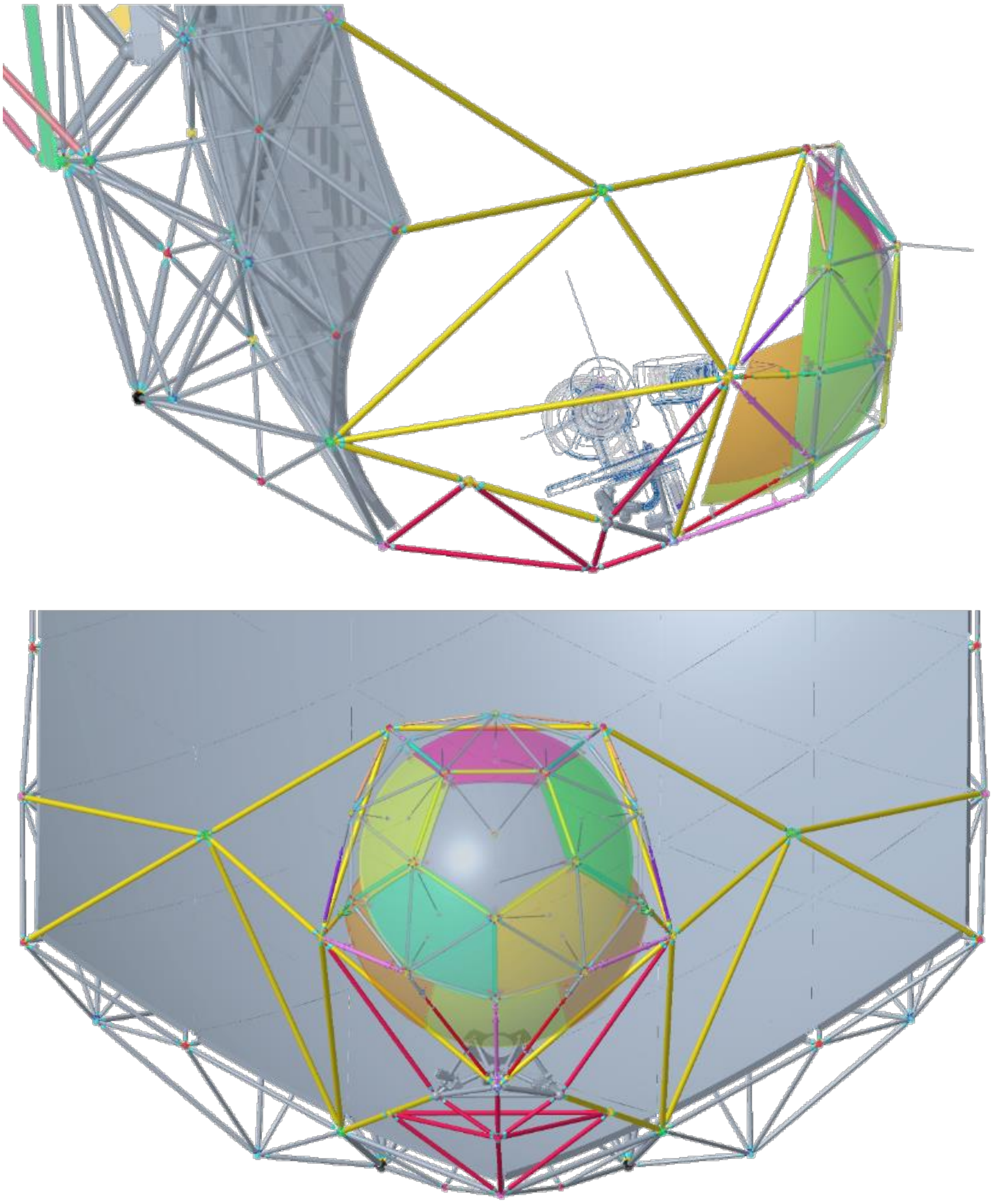


Figure 90: Arm Structure Diagram

3.2.4.7.2 Feed Indexer Stewart Supporting Structure

The feed indexer Stewart supporting structure can achieve ±30mm adjustment in X/Y/Z directions and $\pm 0.2°$ rotational adjustment of feed indexer. The bottom of Stewart is connected with three

knots on the arm and the upper of Stewart is connected with feed indexer supporting interface flange, as shown in Figure 91. The whole supporting structure is steel material.
Position of the feed indexer can be adjusted by motors or manually and locked by the reducer on each bar when finished. Motors on the supporting bars will be removed after the adjustment.

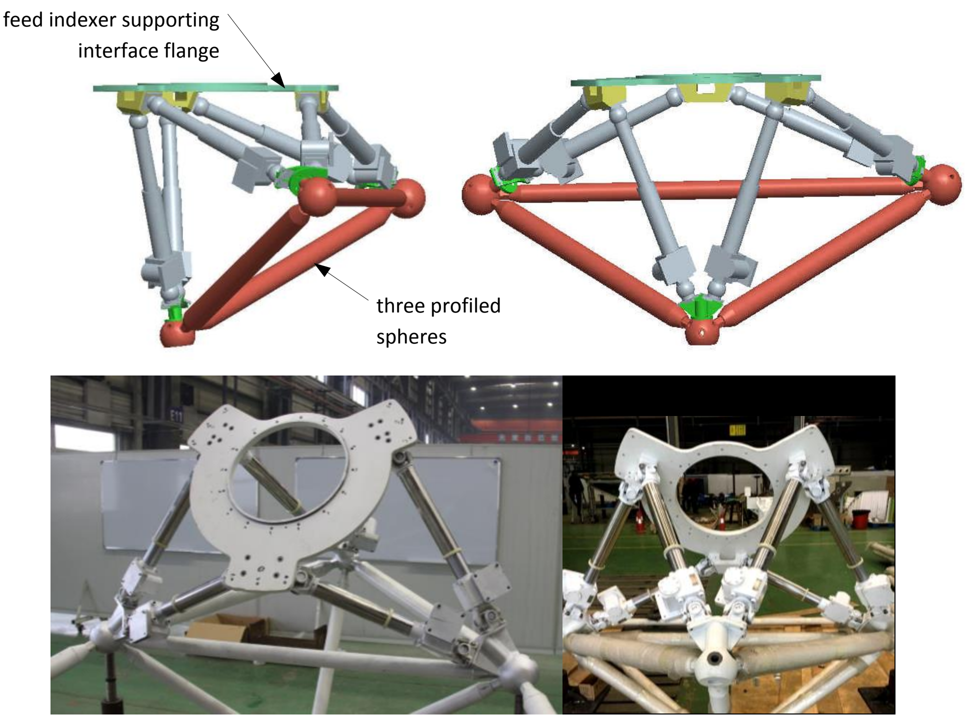


Figure 91 Feed indexer Stewart supporting structure

3.2.4.7.3 Subreflector Sterwart Structure

As shown in Figure 92, the subreflector Sterwart structure used between the arm structure and the subreflector BUS is an adjusting & fixing structure, which consists of 15 supporting tubes. Among these tubes, 6 hexapod-type tubes with spherical hinges or knuckle bearings and pin connections are used to achieve the position and rotation adjustment range for subreflector and the other 9 tubes are adjustable in length for increasing the stiffness of the connection between subreflector BUS and arm. Types of the tubes are shown in Figure 93 and Figure 94. Besides, Adjustment screws for the extension of the subreflector are attached on the tubes. The Sterwart structure is also steel material.

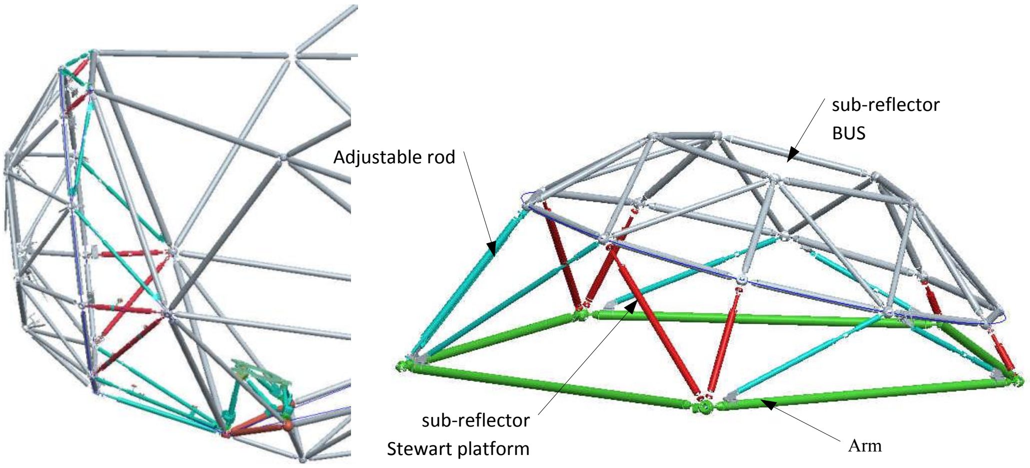


Figure 92 Detail structure of sub-reflector BUS Stewart

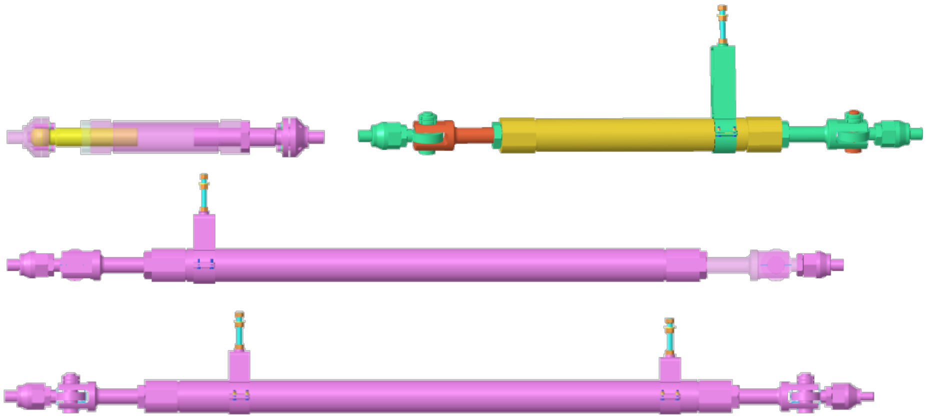


Figure 93 Four types of the hexapod-type tubes

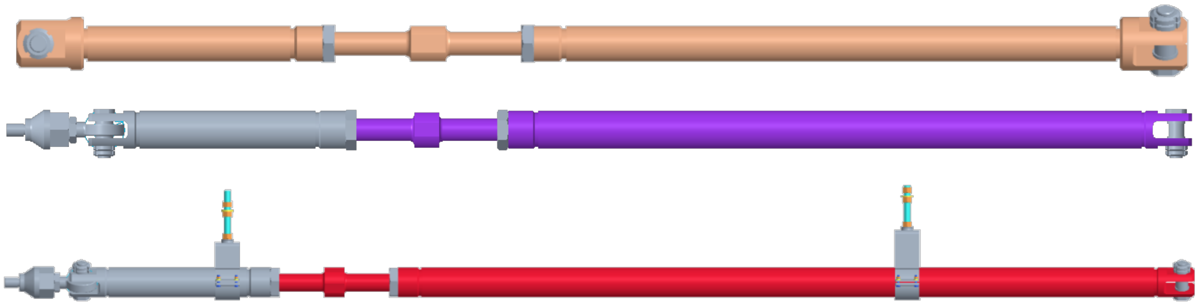


Figure 94 Three types of the adjustable tubes in length

3.2.5 Indexer

3.2.5.1 Feed Indexer Main Components

In the figures below the feed indexer is shown from two different points of view. All the main devices located on the platform are indicated.

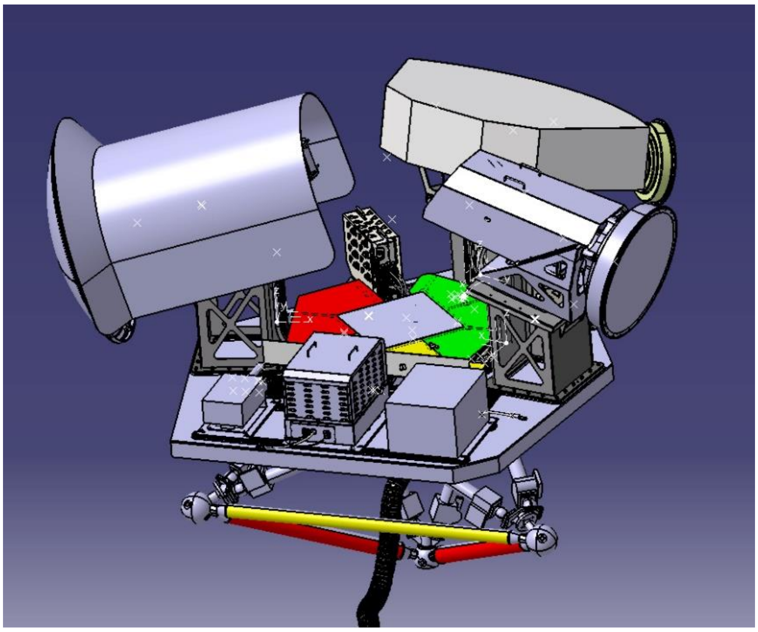


Figure 95 Feed Indexer View 1

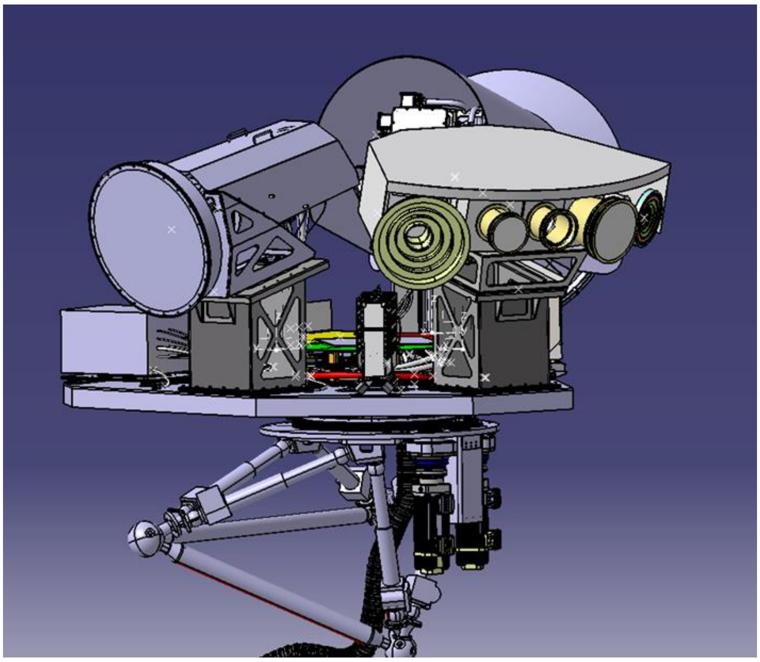


Figure 96 Feed Indexer view 2

In the figure below there is a view from above of the feed indexer.

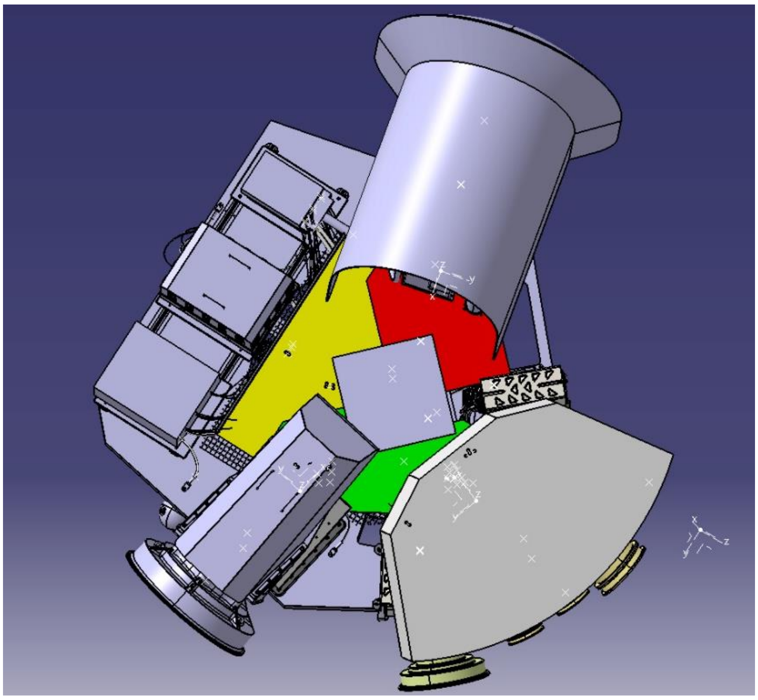


Figure 97 Feed Indexer view from above

A bottom view of the feed indexer is shown below. In this figure is possible to see the two motors, the cable wrap and the hexapod through which the Feed Indexer is connected to the main structure of the telescope.

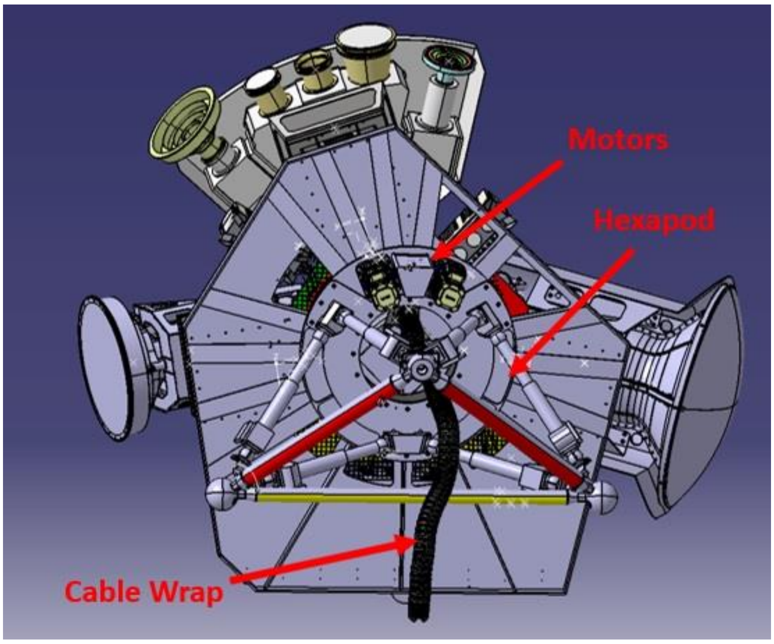


Figure 98 Feed Indexer bottom view

3.2.5.2 Feed Indexer Main Platform and Payloads

In the following tables, the main platform elements are listed.

Table 6 Feed Indexer Platform elements

Main Platform Assembly	
Main Platform	
	Upper structure
	Lower structure
Gear Wheel	

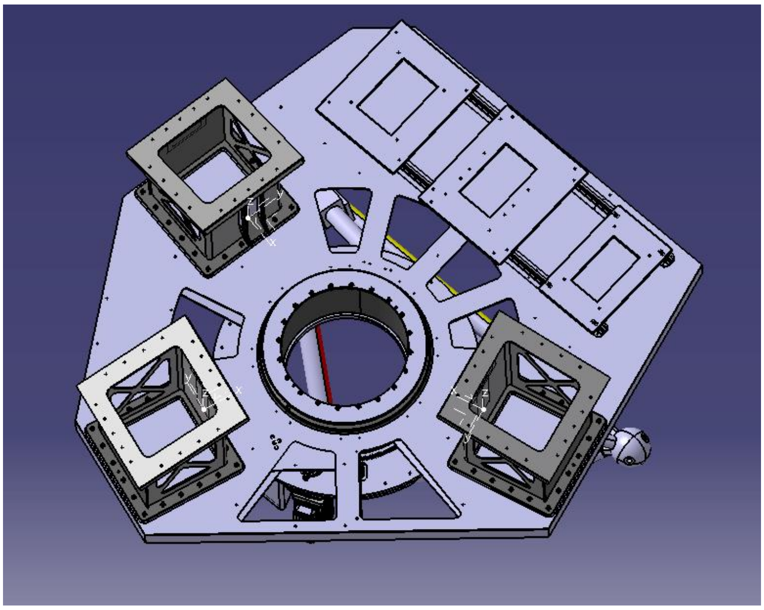


Figure 99 Feed Indexer Platform

While in the next table are listed the devices installed on top of the platform.

Table 7 Payloads installed on the platform

Indexer Power Distribution Panel
SPF Band 1
SPF Band 2
SPF Band 3-4-5
RXS 1-2-3
RXS 4-5
Fiber Routing Panel
Power Distribution Box

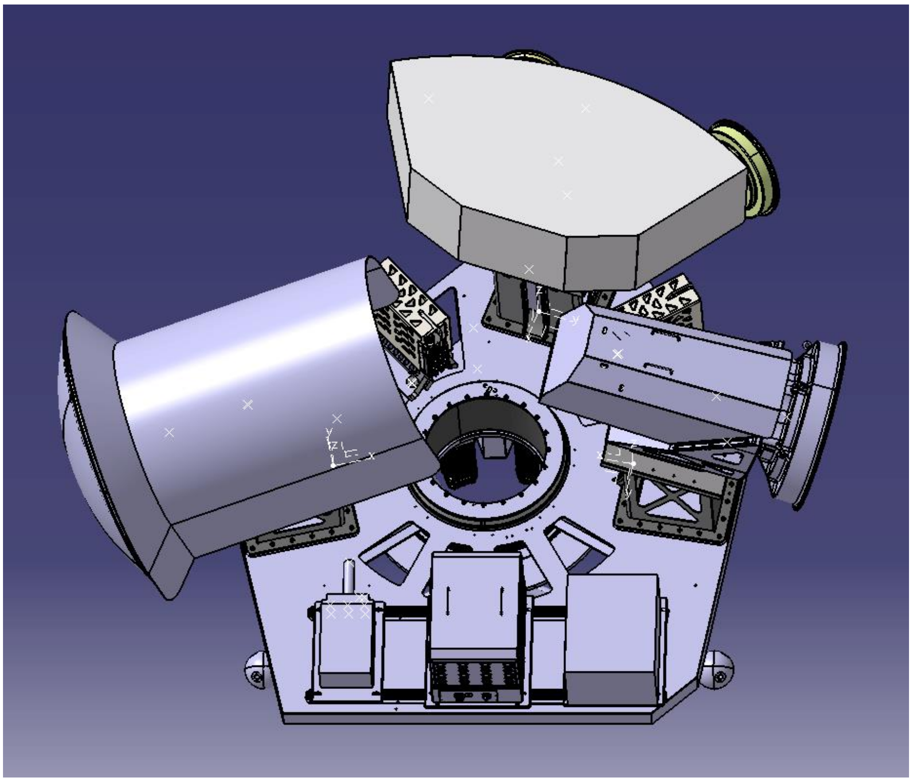
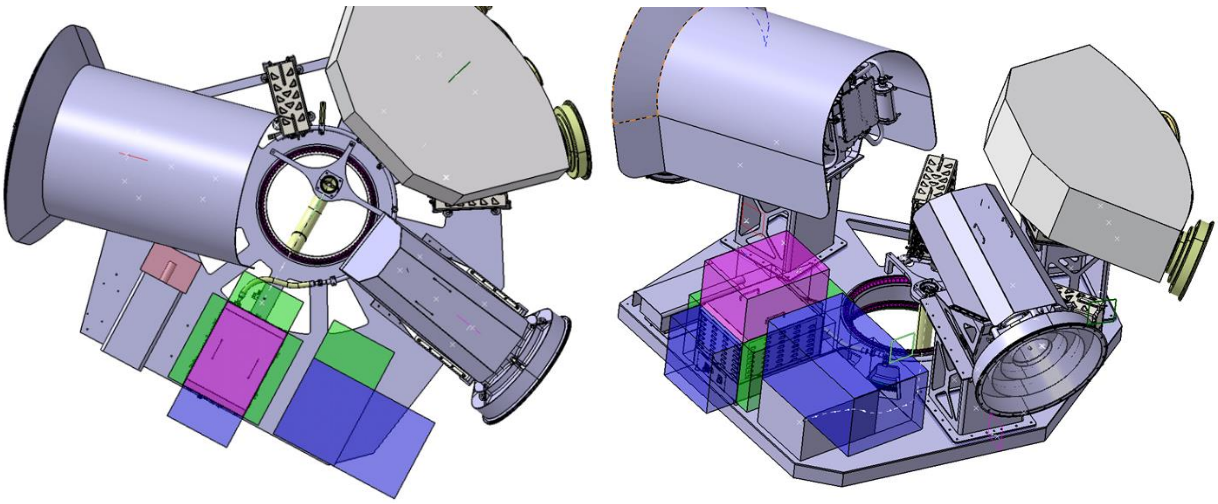


Figure 100 Devices installed on top of the platform

Keep Out Zones

The keep out zones of the equipment installed on the platform have been defined according to the requirements.

Below the keep out zones of the DFN, Vacuum Pump, Power Distribution and Receivers are shown:



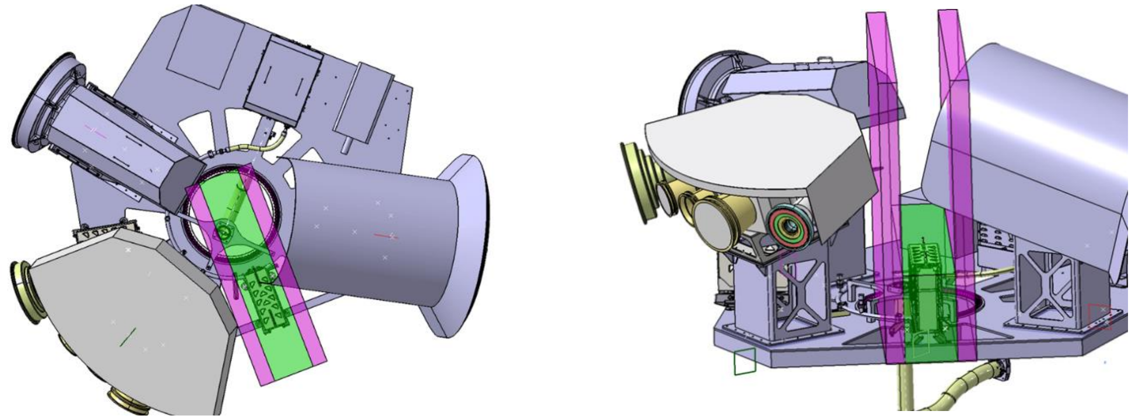


Figure 101 Devices Keep Out Zones

The SPF’s keep out zones have been taken into consideration too:

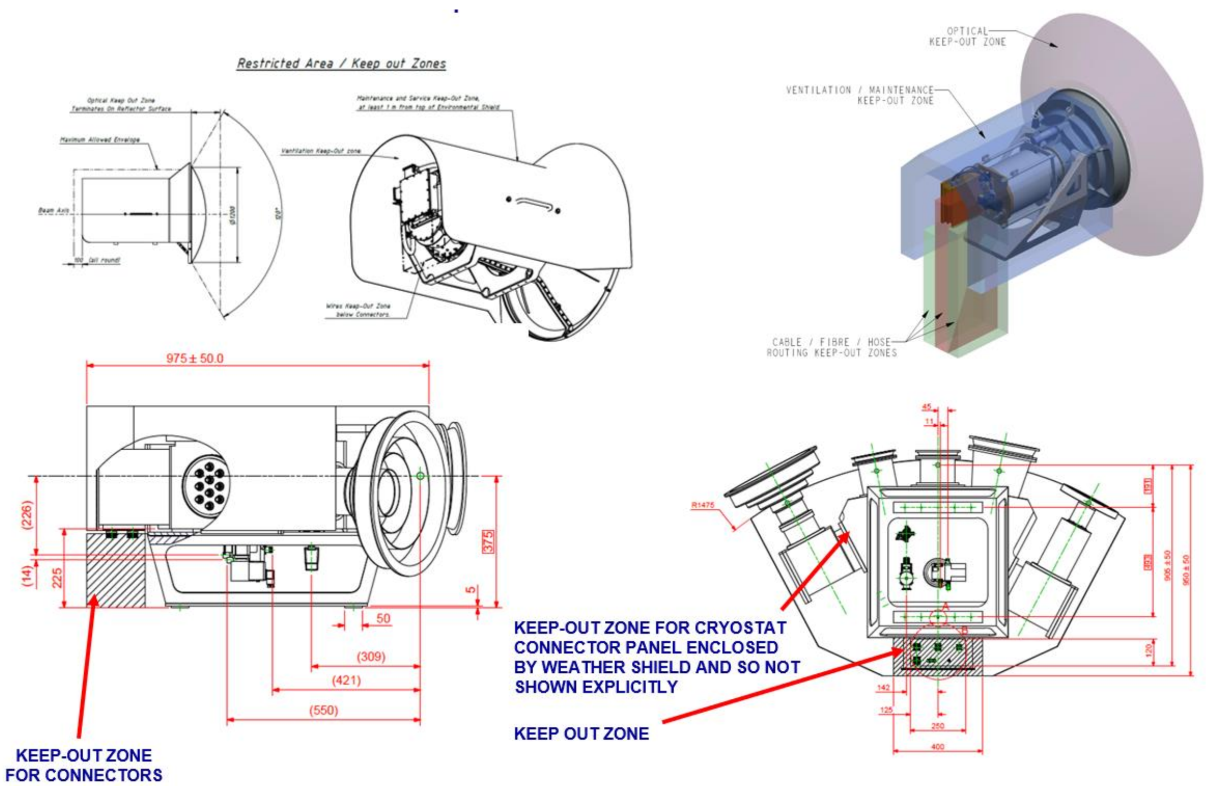


Figure 102 SPF’s Keep Out Zones

3.2.5.3 Weight of the Indexer Assembly with Payloads

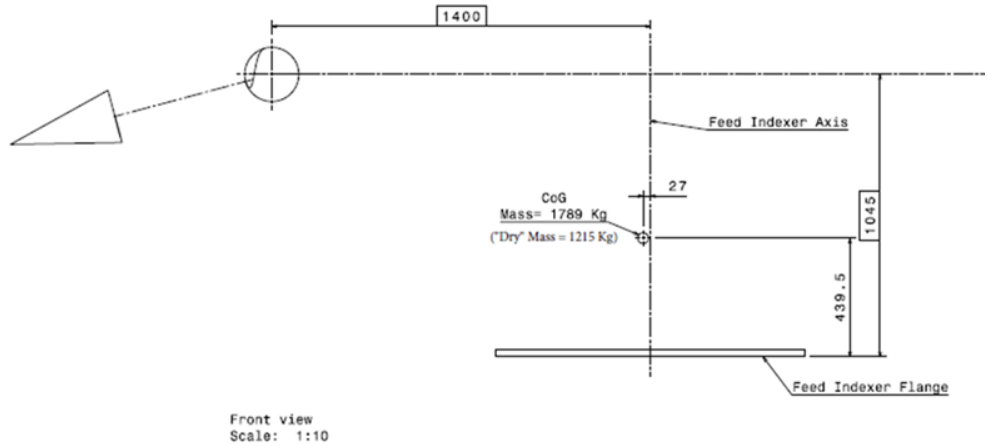
SKA_MID Feed Indexer components and weights are listed in the following table:

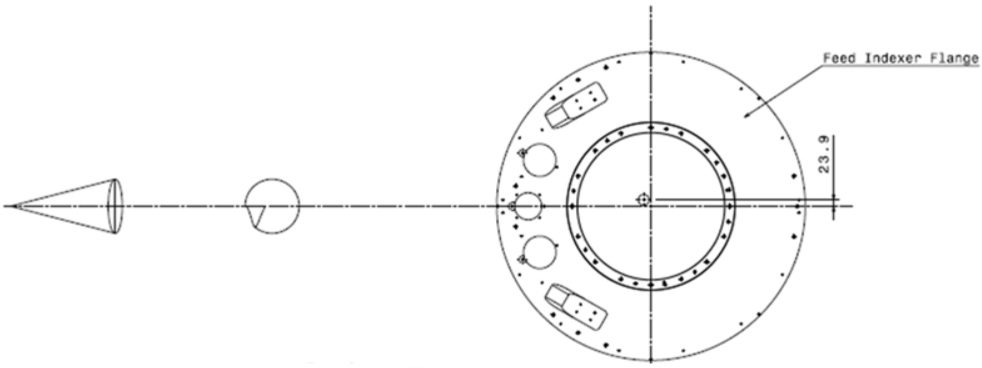
Table 8 Feed Indexer components and total weight

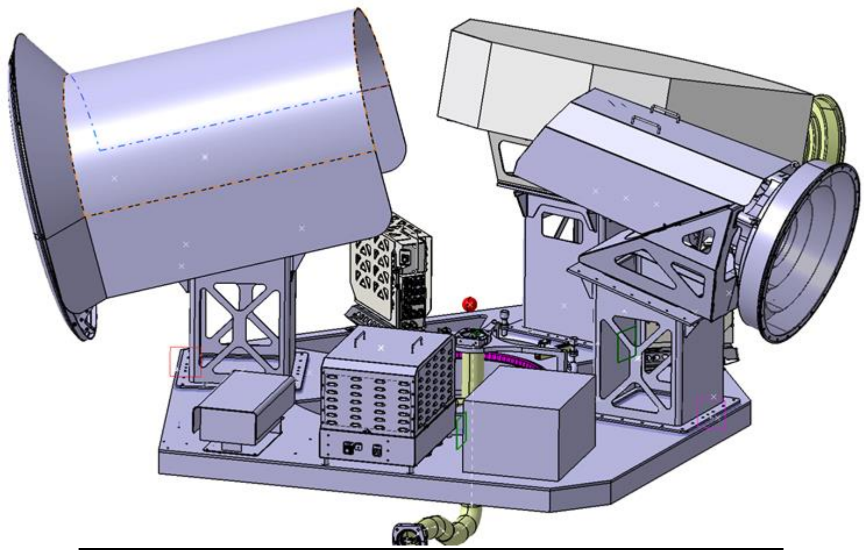
Item	Type	Quantity	Assembly Mass [kg]
Indexer	Develop	1	**1215**
Mounting Interface &Motors support Assembly	Develop	1	
Central Tube Assembly	Develop	1	
Bearings System Assembly	Develop	1	DDR mass; 1.403 Kg (+15%)
Main Platform Assembly	Develop	1	
Maintenance Walkable Platform			
Driving Indexer System	Develop	1	
Harness Support & Protections	Develop	1	
Equipment Mounts	Develop	1	
Limit Switches & Hard Stops	Develop	1	
Dust & RF Protections	Develop	1	
Cable Wrap	COTS	1	
			574
SPF Band 1 system		1	165,0
SPF Band 2 system		1	85
SPF Band 345 system		1	165,0
RXS123		1	30,0
RXS45		1	30,0
Vacuum Pump		1	50,0
FIBRE ROUTING PANEL		1	12,0
BOX POWER DISTRIBUTION		1	7,0
HELIUM PIPES		1	30,0

CoG Calculation

Below the CoG of the FI is indicated, it has been calculated considering the equipment installed.







Center of Mass Position- Center of rotation (ΔX, ΔY)		
	ΔX (mm)	ΔY (mm)
Zero reference angle (SPF 345)	-27,00	23,90
Position 1 (99,97°, SPF2)	-5,54	-0,03
Position 2 (-103,37°, SPF1)	-40,27	0,30

Figure 103 FI CoG

3.2.5.4 Bearings

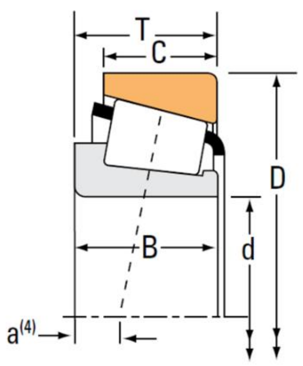
In order to allow the relative rotation between the main platform and Feed Indexer interface, a tapered roller bearing, single-row, TSF configuration ("TSF - SINGLE-ROW, WITH FLANGED OUTER RING") has been chosen. This type of bearing can manage large axial forces as well as being able to sustain large radial forces. The TSF type is a variation on the basic single-row bearing. TSF bearings have a flanged outer ring to facilitate axial location and accurately aligned seats in a through-bored housing. A commercial off-the-shelf item has been chosen and it is detailed below. The weight is around 16.93 Kg.
In the table below the mechanical characteristics of the chosen bearing are listed.

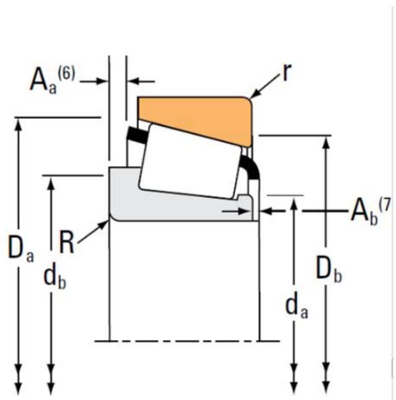
Bearing Dimensions			Load Ratings							Part Number	
Bore d	O.D. D	Width T_1	C_1 (1)	e	Y (2)	C_{90}	C_{a90} (3)	K (2)	Static C_0	Inner	Outer
mm in.	mm in.	mm in.	N lbf			N lbf	N lbf		N lbf		
596.900 23.5000	685.800 27.0000	13.492 0.5312	344000 77300	0.53	1.14	89200 20000	80400 18100	1.11	963000 217000	680235	680270-B

Bearing Dimensions								Housing	Geometry Factors			Bearing Weight
					Shaft							
Width B	Width C	Eff. Ctr. a(4)	Outer Ring Flange O.D. D_1	Flange Width C_2	Max Shaft Fillet Radius R(5)	Backing Shoulder Dia. d_a	d_b	Backing Shoulder Dia.	G_1	G_2	C_g	
mm mm	mm	mm	mm		mm mm	mm		mm in.				kg lbs.
31.750 7.142 1.2500	25.400 1.0000	96.0 3.78	692.841 27.2772		3.5 615.0 0.14	615.0 24.21		669.0 26.34	3739.1 0.2225	1810.4		16.93 37.33

Table 9 Bearing characteristics

(1) Based on 1 x 106 revolutions L10 life, for the ISO life-calculation method.
(2) Consult catalogs.
(3) Based on 90 x 106 revolutions L10 life, for the life-calculation method. C90 and Ca90 are radial and thrust values.
(4) Negative value indicates effective center inside cone (inner-ring) backface.
(5) These maximum fillet radii will be cleared by the bearing corners.





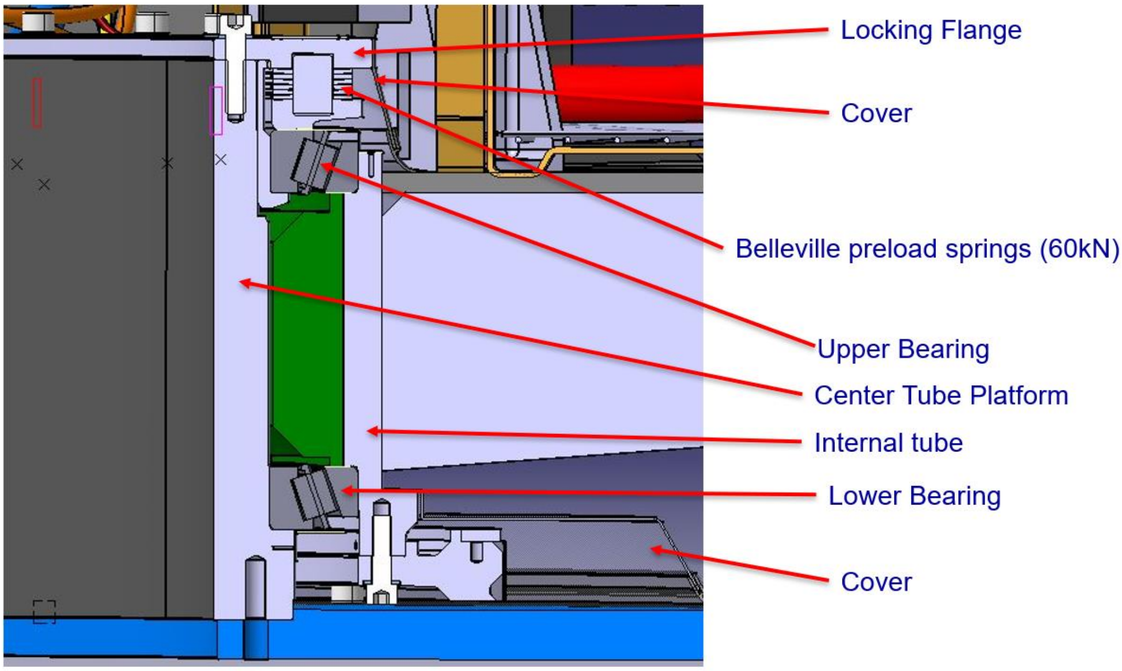


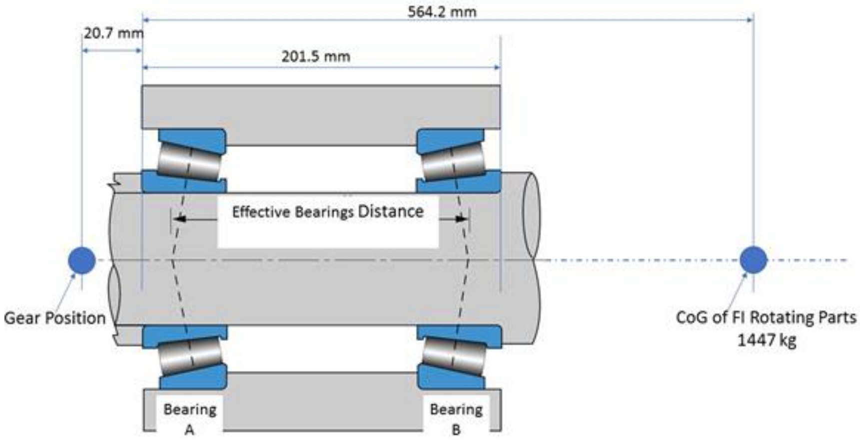
Figure 104 Bearing Installation

Within the table below all the main design data of the bearings are summarized.

Table 10 Bearing design data

BEARINGS TIMKEN TS 680235 - 680270		
Preload definition (FI axis horizontal)		
Bearing A - End Face	0.000	mm
Effective center Bearing A	-96.000	mm
Bearing B - End Face	201.500	mm
Effective center Bearing B	297.500	mm
Platform Mass (Only rotating part of the FI)	1,447.0	kg
CoG axial position from Bearing A End Face	564.200	mm
Gear Contact radial position	414.600	mm
Gear contact axial position	-20.700	mm
Tangential Force	4,023.8	N
Radial Force	1,558.5	N
Axial Thrust	1,464.5	N
Axial Force due to Weight		
Effective Center A - Load application distance	660.200	mm
Effective Center B - Load application distance	266.700	mm
Radial Force on Bearing A	-9,620.9	N
Radial Force on Bearing B	23,816.0	N
Moment Check on Bearing A	0.0	ok
Y bearing A	1.14	[-]
Y Bearing B	1.14	[-]
Axial Force on Bearing A	-4,219.7	N
Axial Force on Bearing B	10,445.6	N
Max Axial Force due to Weight	10,445.6	N

Axial Force due to Tangential Force		
Effective Center A - Load application distance	75.300	mm
Effective Center B - Load application distance	-318.200	mm
Radial Force on Bearing A	3,253.8	N
Radial Force on Bearing B	770.0	N
Moment Check on Bearing A	0.0	ok
Y bearing A	1.14	[-]
Y Bearing B	1.14	[-]
Axial Force on Bearing A	1,427.1	N
Axial Force on Bearing B	337.7	N
Max Axial Force due to tangential force	1,427.1	N
Axial Force due to Radial Force		
Effective Center A - CoG distance	75.300	mm
Effective Center B - CoG Distance	-318.200	mm
Radial Force on Bearing A	1,260.3	N
Radial Force on Bearing B	298.2	N
Moment Check on Bearing A	0.0	ok
Y bearing A	1.14	[-]
Y Bearing B	1.14	[-]
Axial Force on Bearing A	552.7	N
Axial Force on Bearing B	130.8	N
Max Axial Force due to Radial force	552.7	N
Axial Force due to Axial Thrust		
Moment due to Axial Thrust	607,181.7	Nmm
Radial Force on Bearing A	-1,543.0	N
Radial Force on Bearing B	1,543.0	N
Moment Check on Bearing A	0.0	ok
Y bearing A	1.14	[-]
Y Bearing B	1.14	[-]
Axial Force on Bearing A	-676.8	N
Axial Force on Bearing B	676.8	N
Max Axial Force due to Radial force	676.8	N
Total Radial Force on Bearing A	-6,649.9	N
Total Radial Force on Bearing B	26,427.2	N
Max Total Axial Force on Bearing A	-2,916.6	
Max Total Axial Force on Bearing B	11,590.9	
Axial Thrust (applied to bearing axis)	1,464.5	N
Total axial force to eliminate the axial displacement of the rollers	13,055.4	N
Safety factor	2.0	[-]
Minimum Preload	26,110.8	N
Used Preload	45,000.0	N



Working hours definition (FI axis horizontal)		
Axial Force on Bearing A after preload	42,083.4	N
Axial Force on Bearing B after preload	56,590.9	N
e_a (bearing data)	0.53	[-]
e_b (bearing data)	0.53	[-]
Equivalent load P on Bearing A	45,315.1	N
Equivalent load P on Bearing B	75,084.5	N
C_{1a} (bearing data)	344,000	N
C_{1b} (bearing data)	344,000	N
Rotation angle	203.3	°
Time for rotation	30.0	s
Rotational Speed	1.13	rpm
Working hours Bearing A	1.3E+07	hours
Working hours Bearing B	2.4E+06	hours
Duty Factor	5.0%	%
Working years Bearing A	>50	years
Working years Bearing B	>50	years

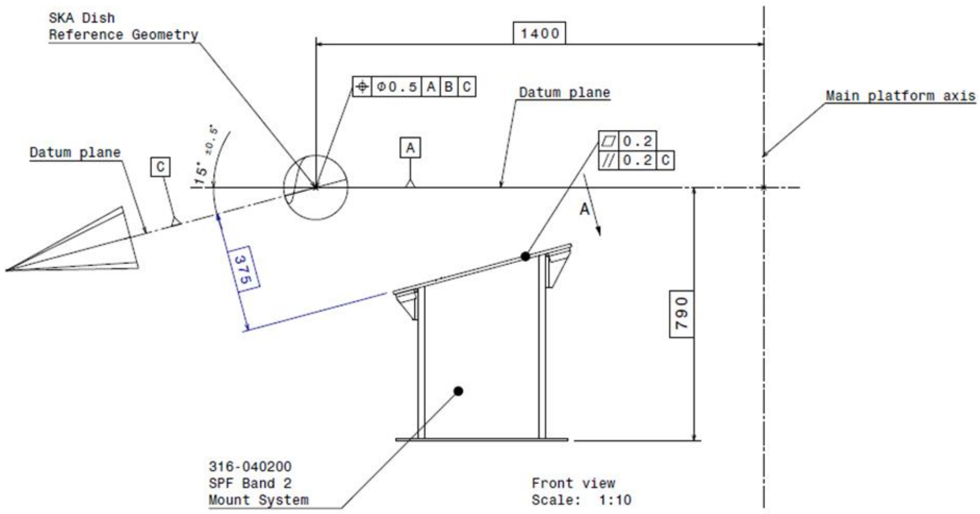
Working hours definition (FI axis vertical)		
Axial Force on Bearing A after preload	59,195.1	N
Axial Force on Bearing B after preload	30,804.9	N
Equivalent load P on Bearing A	67,482.4	N
Equivalent load P on Bearing B	35,117.6	N
C_{1a} (bearing data)	344,000	N
C_{1b} (bearing data)	344,000	N
Rotation angle	203.3	°
Time for rotation	30.0	s
Rotational Speed	1.13	rpm
Working hours Bearing A	3.4E+06	hours
Working hours Bearing B	3.0E+07	hours
Duty Factor	5.0%	%
Working years Bearing A	>50	years
Working years Bearing B	>50	years

3.2.5.5 Interface system

3.2.5.5.1 Interface with SPFs

Below the drawings which indicate the interfaces between the Feed Indexer and the SPFs (Band1, Band2 and Band345) are shown.

As it is possible to see below only one support is shown, this is because the three supports are identical to each other, it means that the interfaces between the supports and each SPFs are the same.



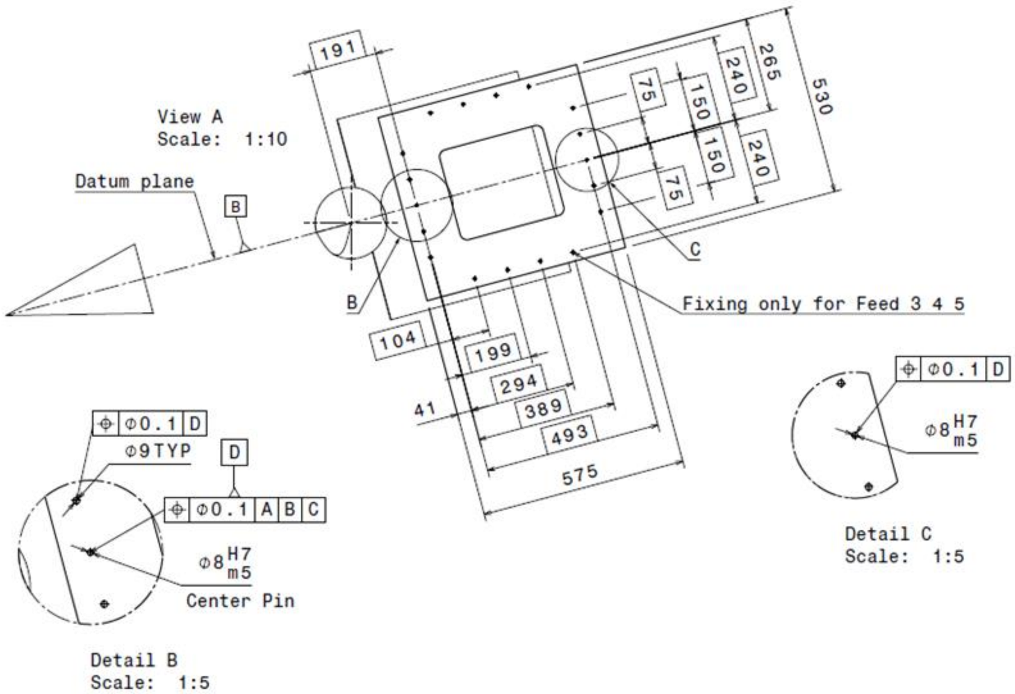
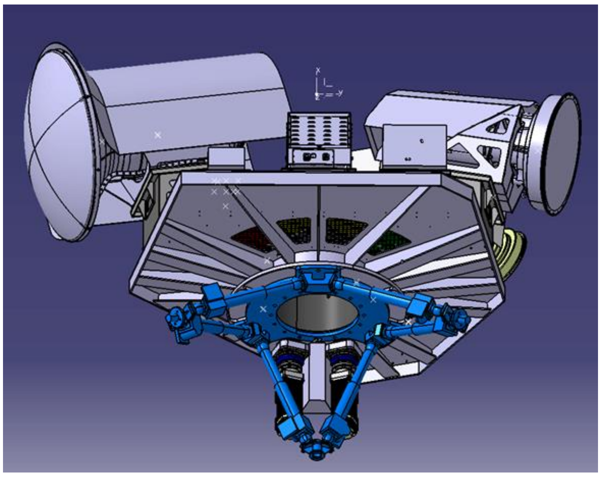
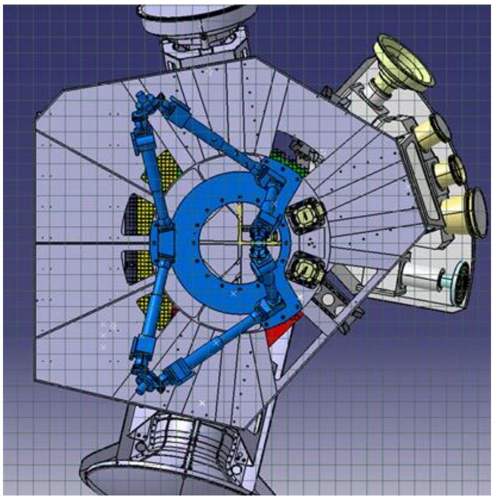


Figure 105 Interface with SPFs

3.2.5.5.2 Interface with the Telescope Structure

Below you can see how the Feed Indexer is connected to the telescope structure (blue in the figures).





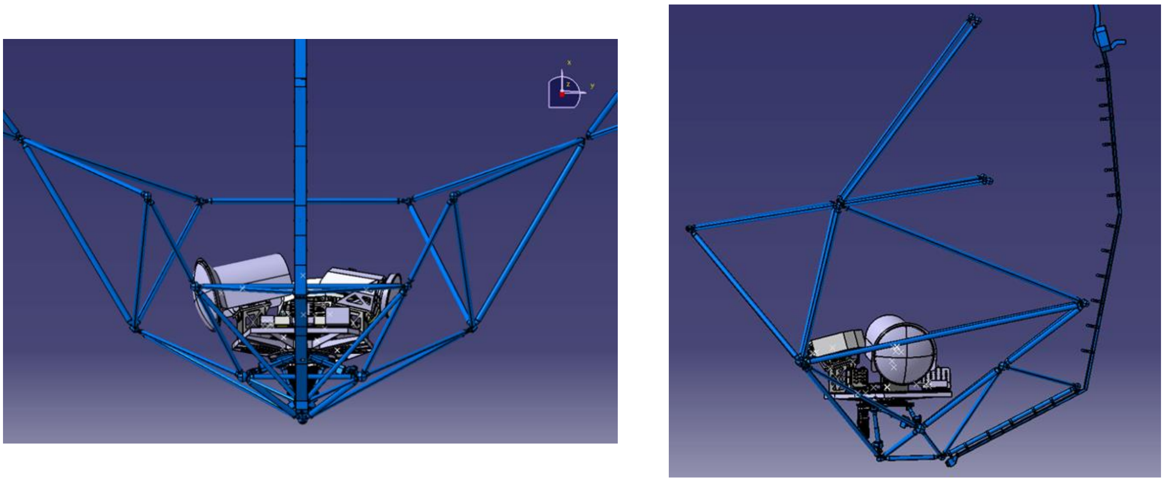


Figure 106 Interface FI-Telescope Structure

The feed Indexer is connected to the hexapod and then to the telescope structure through a flange, the yellow one in the following figure:

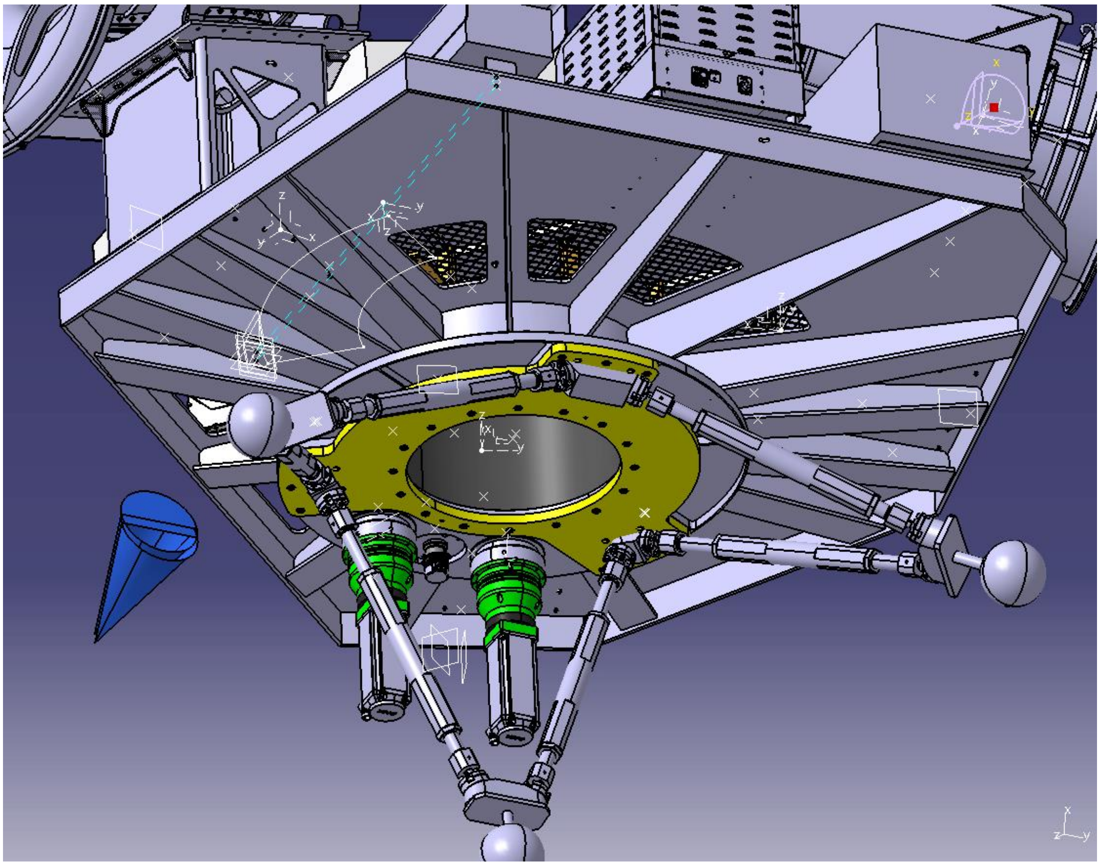


Figure 107 Interface Flange

Below the drawing which indicates the interfaces between the Feed Indexer and the elevation assembly is shown.

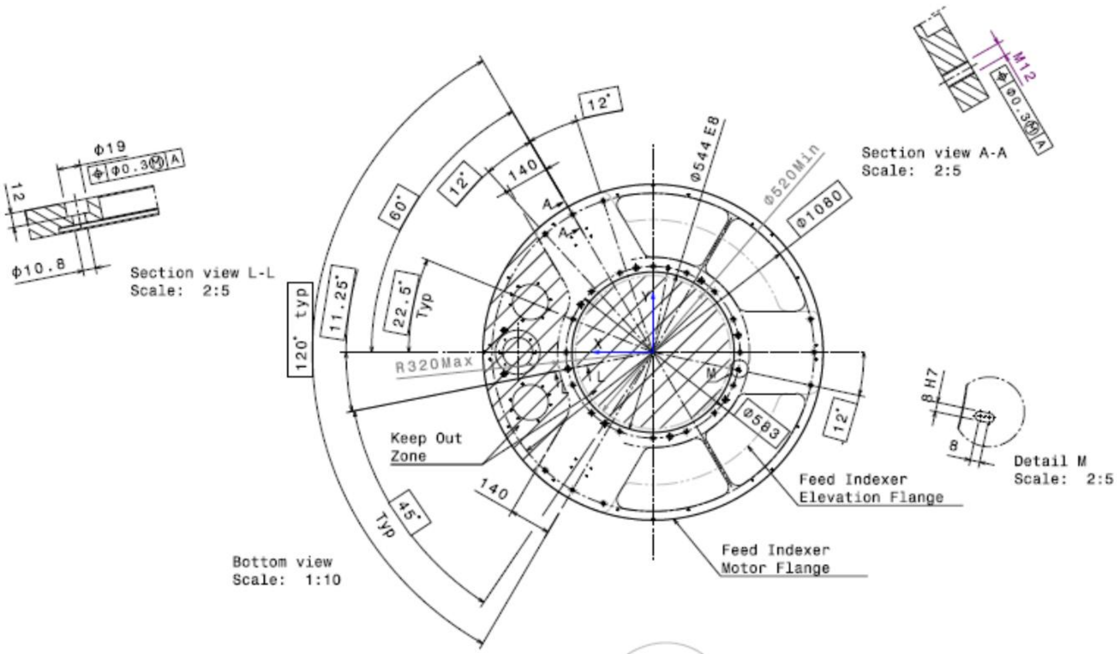


Figure 108 Interface with the telescope structure

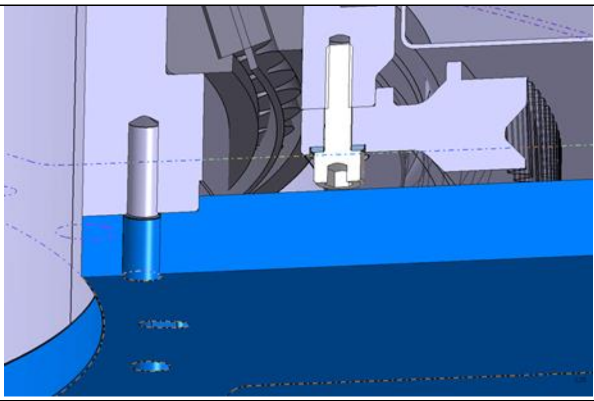
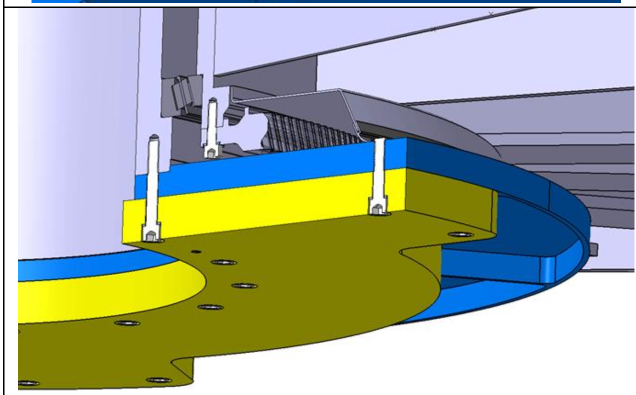
	16 holes (M12) allow the connection between the inner tube flange and the elevation structure
	16 M12 Bolts connect the Elevation Structure flange with the Inner Tube flange Bolts preload = 50 kN Bolts Strenght Grade: ISO 898-1 – Grade 10.9 9 M12 Bolts connect the Elevation Structure flange with the Motor flange (to increase the stiffness) Bolts preload = 50 kN Bolts Strenght Grade: ISO 898-1 – Grade 10.9

Figure 109 Interface with the telescope structure: design details

3.2.5.6 Platform Rotation mechanism

Because of dynamic friction generated by the tooth-tooth contact, residual mechanical backlash, rounding errors in the reduction ratios, the transmission of motion can submit the axis of electro-

mechanical errors of positioning, which can accumulate, introducing a drift with respect to the reference position. To overcome a multi-engine system structured in pair has been selected. This way, the precise contact between the gears is guaranteed. Each axis incorporates two motors in a symmetrical configuration, and coupled via toothed rings main axis. The motors are controlled in pairs and the “torque” of preload is applied to each pair of motors to eliminate backlash (drag error), and a tooth-tooth mechanical backlash. This “preload torque” is achieved through a software algorithm, inserted in the axis control scheme. It regulates the torque of each motor based on acceleration and torque required by the system.
In order to apply the torque preload, we need to adjust the torque via SW, and the control system must be done in order to control the motor by imposing the torque from the driver (i.e. a “closed system” in which only is imposed the position, is not applicable).
Therefore, the system can be dimensioned studying the torque required at each angular position of the Feed Indexer.

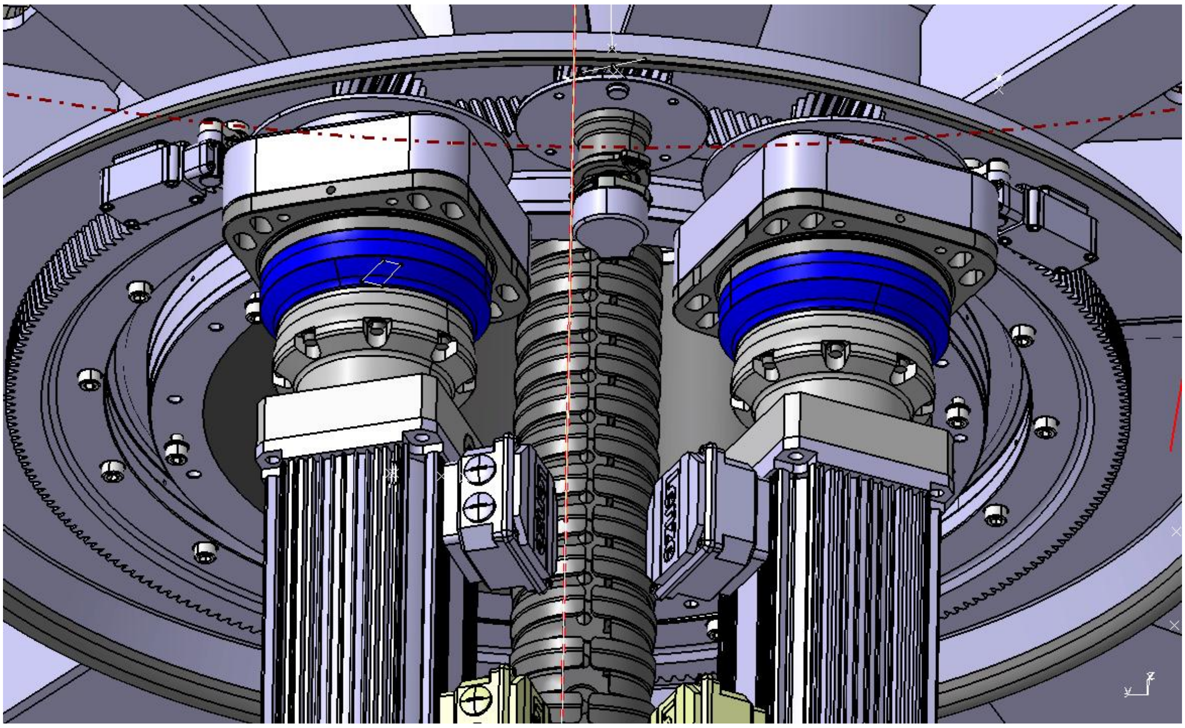


Figure 110 Platform Rotation mechanism

The following table shows the main geometric parameters of the system, the mass, the minimum speed required to meet the requirements related to the SPF-band exchange rate.

Table 11 Geometric parameters of the system

Platform Rotating mass	**1.518,3 kg**	**kg**
Pinion Pitch Diameter	54.0	mm
Wheel Pitch Diameter	762.0	mm
Reduction Rate	14.11	-
Band 1 Position Angle	103.35	°
Band 2 Position Angle	-99.97	°

Band 3 Position Angle	-47,69	°
Band 4 Position Angle	10,45	°
Band 5A Position Angle	-7,22	°
Band 5B Position Angle	-30,05	°
Band 5C Position Angle	-18.62	°
COG Angle	-144.23	°
COG-Axis distance	57.30	mm
Unbalanced Torque	835.35	mm
Platform rotation speed	**1.36**	**rpm**
Pinion speed (gearbox output shaft)	**19.13**	**rpm**
Time to positioning	**26.0**	**s**

Specifically, the platform has to be able to rotate in both directions respectively of 103.35° and 99.97°, it means that the platform will rotate of 203.32° (total angle).
Feeds positions are shown in following figure:

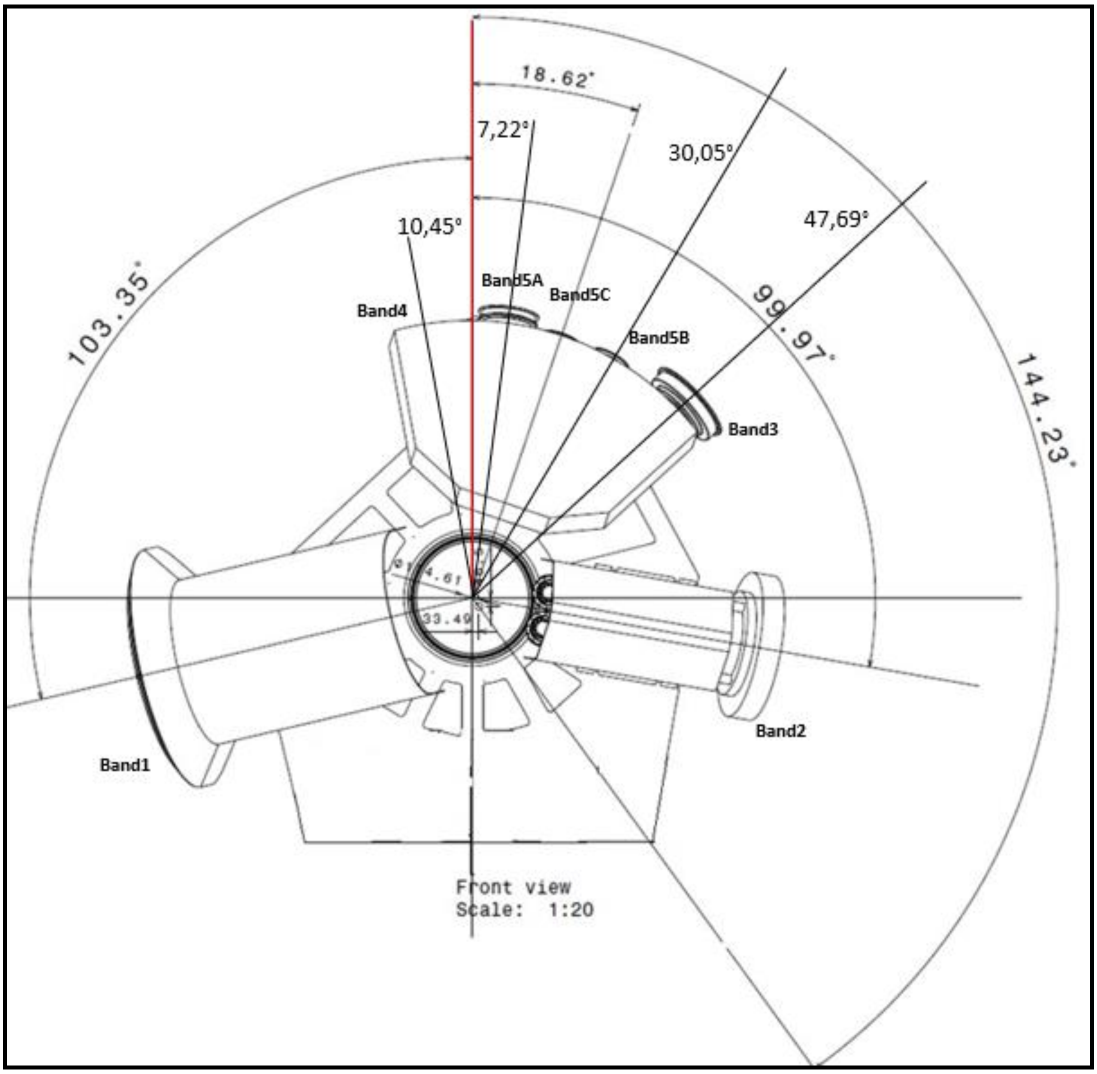


Figure 111 Platform rotation

Torque values in the worst condition (SPF B1 Side, the highest antenna elevation platform position 90°) have been calculated, in order to define the COTS components
Requested torque, for both actuators, is about 1000 Nm. All the parameters needed to select the COTS motors and gearboxes for the Feed Indexer control have been calculated.
The flexibility of the gearbox + motor have been calculated in the different positions of the platform, in order to quantify the elastic force release effects to the focus displacement. The Feed 1/2/345 focus displacement during platform pitching (from 90° to 0°), due to the release of elastic forces in the planetary gearboxes has been verified.
A motor brake is requested to keep the platform in the desired position. The brake also intervenes in case of sudden power failure.

Driveline flexibility

A FE model has been developed to analyze the flexibility (or stiffness) of the driveline, in order to evaluate the positioning error of the Feed Phase Center when platform changes the elevation angle.
In the first phase a preload torque has been applied to the pinions, then the rotation gearbox has been blocked (to simulate the motor brakes) and finally the unbalance torque has been applied to the wheel gear.
A fully non-linear model has been adopted, using non-linear contact between pinions and wheel gear.

In the analyses, as the gravity unbalance was lesser than the torque preload, the teeth of both pinions remain always in contact with the wheel gear.
In the next page the results of the driveline flexibility analyses have been reported.

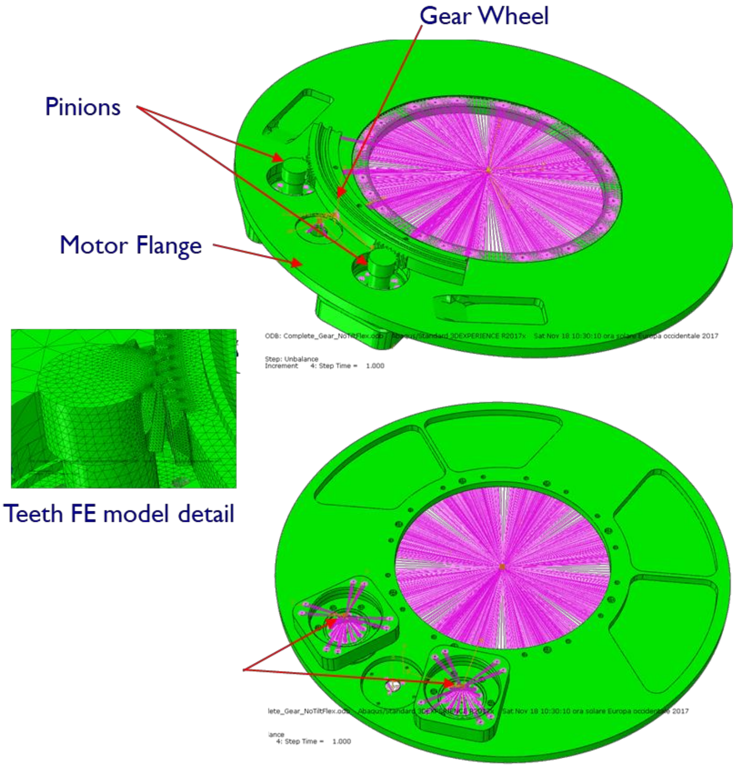


Figure 112 Driveline flexibility

Table 12 Driveline flexibility design data

Flexibility = Rotation of the Platform divided by the unbalance torque					
		Start rotation	Final rotation	Rotation due to unbalance	Total Flexibility
Simulation Configuration		[rad]	[rad]	[arcsec]	[arcsec/Nm]
A	Only Pinions and Wheel Gear deformation	-2.147E-04	-1.787E-04	7.427E+00	8.697E-03
B	Case A + supporting structure deformation	-2.399E-04	-1.981E-04	8.619E+00	1.009E-02
C	Case B + Gearbox tilting deformation	-2.538E-04	-2.086E-04	9.320E+00	1.091E-02
D	Case C + Gearbox Torsional deformation	-2.898E-04	-2.347E-04	1.137E+01	1.331E-02

Single contributions to total flexibility	Contribution to total Flexibility [arcsec/Nm]	Contribution to total Flexibility [%]
Pinions and Wheel Gear	8.697E-03	65.3%
Supporting Structure	1.396E-03	10.5%
Gearbox tilting flexibility	8.212E-04	6.2%
Gearbox torsional flexibility	2.395E-03	18.0%
Total Flexibility	**1.331E-02**	

Effect of the Driveline flexibility on the Feed Indexer position & orientation - R.FI.03 & R.FI.04 (This errors must be added to those reported in table at pag 52)	Maximum unbalance variation during full elevation range [Nm] (Rigging angle as reference)	Maximum error in deflection (position) (mm)	Maximum error in deflection (orientation) (Deg)	R.FI.03 requirement (position) (mm)	R.FI.04 requirement (deflection) (Deg)
SPF 1 Position	27.59	2.492E-03	1.020E-04	0.5	0.5
SPF 345 Position	226.56	2.047E-02	8.376E-04	0.5	0.5
SPF 2 Position	73.67	6.655E-03	2.724E-04	0.5	0.5

3.2.5.7 Bearings and Gears Maintenance – Lubrication

Proper lubrication is essential to achieve optimum equipment performance, minimum equipment downtime and the longest possible bearing life.
When a properly lubricated bearing rotates, the mating surfaces of the bearing components create a lubricant film that keeps the components separated. The lubricant:

- **Provides a suitable film that prevents metal-to-metal contact and separates the moving parts in a bearing**
- **Carries away heat**
- **Protects the bearing surfaces from corrosion**

The lubrication requirements of all bearings used in general industrial applications can be met with high quality petroleum lubricants. However, synthetic lubricants are gaining considerable popularity, especially where high operating temperatures and long service life is required.
Lubricant types can be broadly divided into two groups; oil or grease. Each has its advantages:

OIL	GREASE
Carries heat away from the bearings	Simplifies seal design and acts as a sealant
Carries away moisture and particular matter	Permits prelubrication of sealed or shielded bearings
Easily controlled lubrication	Generally requires less frequent lubrication

<u>OIL</u>

Oils are classified as either petroleum or synthetic. Petroleum oils are refined from crude oil and synthetic oils are produced by chemical synthesis. The primary characteristic when selecting an oil is its viscosity, a measure of its flow characteristics. Viscosity is normally expressed in terms of the time required for a specific amount of oil to flow through a standard size hole at a specific temperature. Viscosity varies with temperature and is always described with the temperature at which it was measured.
Where heat must be carried away from the bearing, oil must be used, and it is nearly always preferred for very high-speed applications. Other relevant features and advantages of oil lubrication include:

- Oil is a better lubricant for high speeds or high temperatures, and can be cooled to help reduce bearing temperature.
- Oil is easier to handle and to control the amount of lubricant reaching the bearing, but it is harder to retain in the bearing. Lubricant losses may be higher than with grease.
- As a liquid, oil can be introduced to the bearing in many ways such as drip-feed, wick feed, pressurized circulating systems, oil bath or air-oil mist. Each is suited to certain types of applications.

- Oil is easier to keep clean for recirculating systems.

Delivery Systems

Oil may be introduced to the bearing in many ways. The most common systems are:

- Oil bath: The housing is designed to provide a sump or reservoir that the bearing rolling elements rotate through. Generally, the oil level is no higher than the center point of the lowest rolling element, as measured when the bearing is stationary. In highspeed applications, lower oil levels are used to reduce churning. Gages or controlled elevation drains are used to achieve and maintain the proper oil level.
- Circulating system: A typical oil system consists of an oil reservoir, pump, piping and filter. A cooler may also be required. These systems ensure an adequate supply of oil for both cooling and lubrication.
- Contaminants and moisture are removed from the bearing by the flushing action of the oil, and filters trap contaminants. It is relatively easy to direct lubricant to multiple bearings in the application. The relatively large oil reservoir reduces lubricant deterioration, increasing lubricant life and system efficiency.
- Oil-mist: These systems are used in high speed and continuous operation applications such as steel mill bearings and high-speed machines. They permit close control of the amount of lubricant reaching the bearings and use relatively little oil. The oil may be metered, atomized by compressed air and mixed with air, or it is picked up from a reservoir using a Venturi Effect.

GREASE

Lubricating grease is a solid-to-semi fluid product that includes a thickening agent dispersed in a liquid lubricant. The thickener acts as a sponge and releases oil under load to lubricate the bearing. Additional additives are typically included to change the performance or characteristics of the grease. There is no universal bearing grease. Each individual grease has certain limiting properties and characteristics. Table below shows some of the primary characteristics for each of the most common grease types. The dropping point is the temperature at which the grease liquifies. Some greases are reversible and will reconstitute after the temperature cools to below the dropping point. Other greases will not. In addition to these traditional greases, synthetic lubricating fluids such as esters, organic esters and silicones are capable of performing at temperatures as low as -70°C (-100°F) to as high as 290°C (550°F). Regarding the thickeners, polyurea is a significant lubrication development. Polyurea grease performance is outstanding in a wide range of bearing applications, and in a relatively short time has gained acceptance as a factory packed lubricant for ball bearings.

Temperature and grease life

Greases are rated to perform up to certain upper temperature limits. The Usable Temperature (Table below) is the temperature at which a bearing can continuously operate with no relubrication. Brief intervals of higher temperature operation will probably not result in any lubrication problems. Extended operation above the usable temperature can degrade the grease and result in premature bearing damage. At the dropping point, the grease liquefies and no longer provides adequate lubrication. Some greases are reversible and will reconstitute after the temperature cools to below the dropping point. Other greases will not. The dropping point of the grease used should be at least 40°C (100°F) greater than the highest expected temperature in the application. The high temperature limit for grease is generally a function of the thermal and oxidation stability of the lubricant and the effectiveness of oxidation inhibitors included in grease. As the temperature increases, viscous or hard residues are created that interfere with the operation of the bearing. In general, the higher the temperature the more rapidly the grease oxidizes. As a rule of thumb, grease life is halved for every 10°C (18°F) increase in temperature. For example, if a particular grease provides 2000 hours of life at 90°C (194°F), raising the temperature to 100°C (212°F) would reduce life to approximately 1000 hours. On the other hand, 4000 hours could be expected by lowering the temperature to 80°C (176°F).

Thickener	Typical Dropping PT	Usable Temperature [1]	Typical Water Resistance
	°C °F	°C °F	
Sodium Soap	260 + 500 +	121 250	Poor
Lithium Soap	193 380	104 220	Good
Polyurea	238 460	149 300	Excellent
Lithium Complex Soap	260 + 500 +	163 325	Good

Table 13 Greases Characteristics

Grease application methods

Grease, in general, is easier to use than oil in industrial bearing lubrication applications. Bearings that are initially packed with grease require only periodic relubrication to operate efficiently. **Grease should be packed into the bearing so that it gets between the rolling elements.** For tapered roller bearings, forcing grease through the bearing from the large end to the small end will ensure proper distribution. Grease can be easily packed into small- and medium-size bearings by hand. In shops where bearings are frequently regreased, a mechanical grease packer that forces grease through the bearing under pressure may be appropriate. Regardless of the method used, after packing the internal areas of the bearing, a small amount of grease should also be smeared on the outside of the rollers or balls.

Regreasing timing and amount

The two primary considerations that determine the relubrication cycle are operating temperature and sealing efficiency. The less efficient the seals, the greater the grease loss and the more frequently grease must be added**. Grease should be added any time the amount in the bearing falls below the desired amount. The grease should be replaced when its lubrication properties have been reduced through contamination, high temperature, water, oxidation or any other factors.** It is important to use the proper amount of grease in the application. In typical industrial applications, **the voids in a roller bearing should be filled from one-third to two-thirds with grease. Less grease will result in the bearing being starved for lubrication. More grease may create churning which generates additional heat.**

As the grease temperature rises, its viscosity decreases and becomes thinner. This can reduce the lubricating effect while increasing leakage of the grease from the bearing. It may also cause the grease components to separate, causing the grease to break down. Also, as the bearing heats up, the grease will expand somewhat and be purged from the bearing. However, in low speed applications where temperature is not an issue, the housing can be entirely filled with grease. This safeguards against the entry of contaminants. For best results, there should be ample space in the housing to allow room for excess grease to be thrown from the bearing. However, it is equally important that the grease be retained all around the bearing. If a large void exists between the bearings, grease closures should be used to prevent the grease from leaving the bearing area. During periods of non-operation, it is often wise to completely fill the housings with grease to protect the bearing surfaces. Prior to subsequent operation, the excess grease should be removed and the proper level restored. Applications using grease lubrication should have a grease fitting and a vent at opposite ends of the housing near the top. A drain plug should be located near the bottom of the housing to allow purging the old grease from the bearing.

In the following table the characteristics of the maintenance that must be carried out on the bearings installed on the feed indexer are listed:

Item To Be Maintained	Type of Maintenance	P/C	Duration [h]	Intervals	Qualification	No. of Personnel	Procedure	Section	Description
Indexer Bearings	Lubrication	PM	0,5	2 years	Engineer or skilled mechanical technician	1	Lubrication check of Indexer bearings	PM-04	check the lubrication of the Indexer bearings

Table 14 Feed Indexer bearings maintenance characteristics

Considering the environment in which the bearings will work (see the table below), climatic conditions, operating conditions the characteristics of the bearing maintenance have been defined. Specifically, the lubrication of the two bearings installed on the feed indexer (see the following images) has to be carried out every 2 years by an engineer or a skilled mechanical technician.

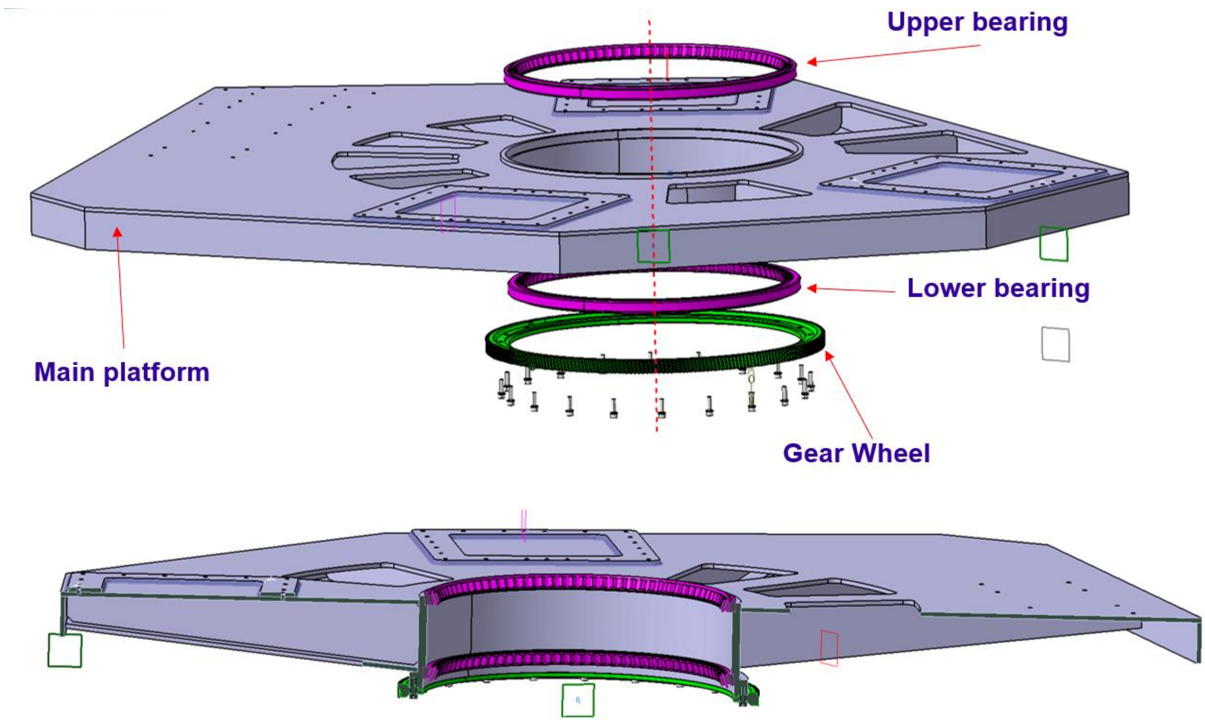


Figure 113 Feed Indexer Bearings

Considering the temperature in which the bearings will work (less than 100° C), the rotation speed of the platform (0,12 rad/s) and the other information about the environment, the lubricant that will be used is a **grease** that will guarantee:

- A simple seal design
- The possibility to carry out a prelubrication of sealed or shielded bearings
- less frequent lubrication

Bearings Lubrication of the SKA Prototypes

The lubrication of the two bearings installed on the feed indexer has to be carried out every 2 years by an engineer or a skilled mechanical technician. Bearings and wheels of the two prototypes SKA-P and SKA-MPI are lubricated by following special greases:

- SKA-P: for the **gears** a grease for weather-proof and vibration-induced bearings, prescribed by the main offshore wind turbine manufacturers Klüberplex BEM 41-141, is used, whose characteristics are shown below. For the **bearings** a grease Klüberplex AG 11-461 is used.

Product data	Klüberplex BEM 41-141
Worked penetration, DIN ISO 2137, 25 °C, upper limit value	340 x 0.1 mm
NLGI grade, DIN 51818	1
Shear viscosity at 25 °C, shear rate 300 s-1, equipment: rotational viscometer, lower limit value	2 000 mPas
Shear viscosity at 25°C, shear rate 300 s-1, equipment:rotational viscometer, upper limit value	4 000 mPas
Kinematic viscosity of the base oil, DIN 51562 pt. 01/ASTM D-445/ASTM D 7042, 40 °C	approx. 130 mm²/s
Kinematic viscosity of the base oil, DIN 51562 pt. 01/ASTM D-445/ASTM D 7042, 100 °C	approx. 14 mm²/s
Corrosion inhibiting properties of lubricating greases, DIN 51802, (SKF-EMCOR), test duration: 1 week, distilled water	<= 1 corrosion degree
Flow pressure of lubricating greases, DIN 51805, test temperature: -35 °C	<= 1 400 mbar
Drop point, DIN ISO 2176, IP 396	>= 250 °C
Minimum shelf life from the date of manufacture - in a dry, frost-free place and in the unopened original container, approx.	36 months

Figure 114 Klüberplex BEM 41-141, product information

- SKA-MPI: for the **gears** a grease AG 11-461, is used, whose characteristics are similar to the grease used on site for Meerkat (MeerKAT uses ROCOL TUFLUBE ALLWEATHER), in order to get the advantage that all the Dishes on site (SKA & MeerKAT) uses similar/compatible greases for easier maintenance during the lifetime. The same grease is used for the **bearings**.

Product data	Klüberplex AG 11-461	Klüberplex AG 11-462	Klüberplex AG 11-462Spray
Article number	039213	039091	081302
Solid lubricants, percentage	approx. 20 % by weight	approx. 20 % by weight	approx. 20 % by weight
Lower service temperature	-20 °C / -4 °F	-10 °C / 14 °F	-10 °C / 14 °F
Upper service temperature	150 °C / 302 °F	150 °C / 302 °F	150 °C / 302 °F
Colour space	white	white	white
Texture	homogeneous	homogeneous	homogeneous
Density at 20 °C	approx. 1.07 g/cm³	approx. 1.05 g/cm³	
NLGI grade, DIN 51818	1	2	
Worked penetration, DIN ISO 2137, 25 °C, lower limit value	310 x 0.1 mm	265 x 0.1 mm	265 x 0.1 mm
Worked penetration, DIN ISO 2137, 25 °C, upper limit value	340 x 0.1 mm	295 x 0.1 mm	295 x 0.1 mm
ISO viscosity grade of the base oil, DIN ISO 3448	460	460	460
Drop point, DIN ISO 2176, IP 396	>= 180 °C	>= 180 °C	>= 180 °C
FZG scuffing test, based on DIN ISO 14635, A/2,76/room temperature, scuffing load stage	>= 12	>= 12	>= 12
Functional lubricant film	approx. -40 °C	approx. -40 °C	approx. -40 °C
Water resistance, DIN 51807 pt. 01, 3 h/90 °C, rating	0 - 90	0 - 90	0 - 90
Minimum shelf life from the date of manufacture - in a dry, frost-free place and in the unopened original container, approx.	24 months	24 months	24 months

Figure 115 Klüberplex AG 11-461, product information

In the following images, a section of the Feed Indexer in which is possible to see the two bearings and specifically the points from which the lubrication is carried out.

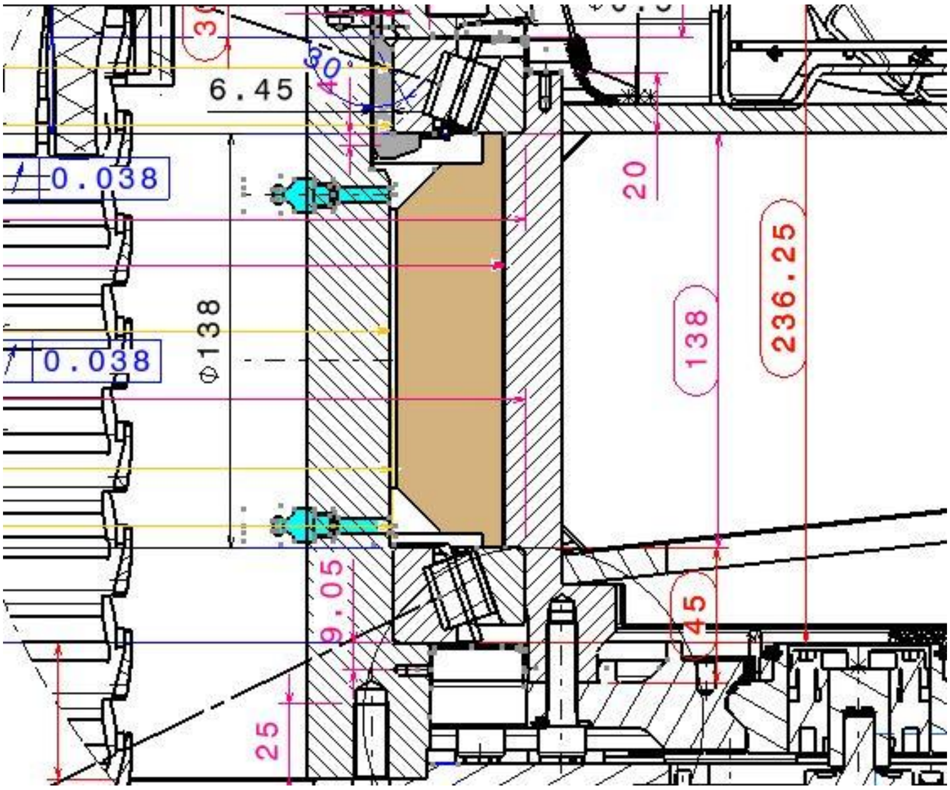
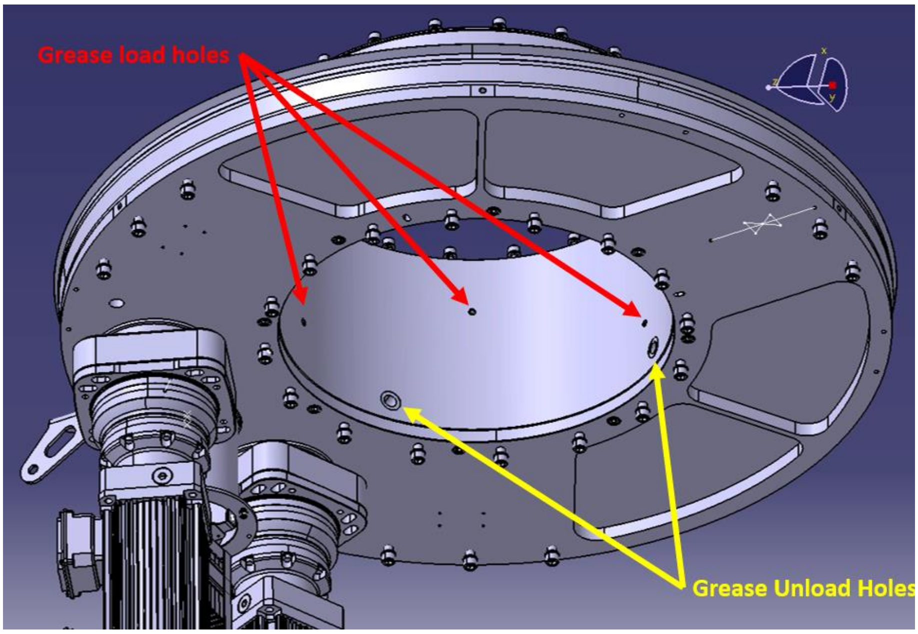


Figure 116 Feed Indexer Bearings lubrication 1

There are 6 lubrication M8 holes at two different heights of the cylinder (120 degrees far from each other on each height), see the figures below. The grease is loaded through the six M8 holes indicated in red. If neede, the grease is unloaded through the four holes indicated in yellow below.



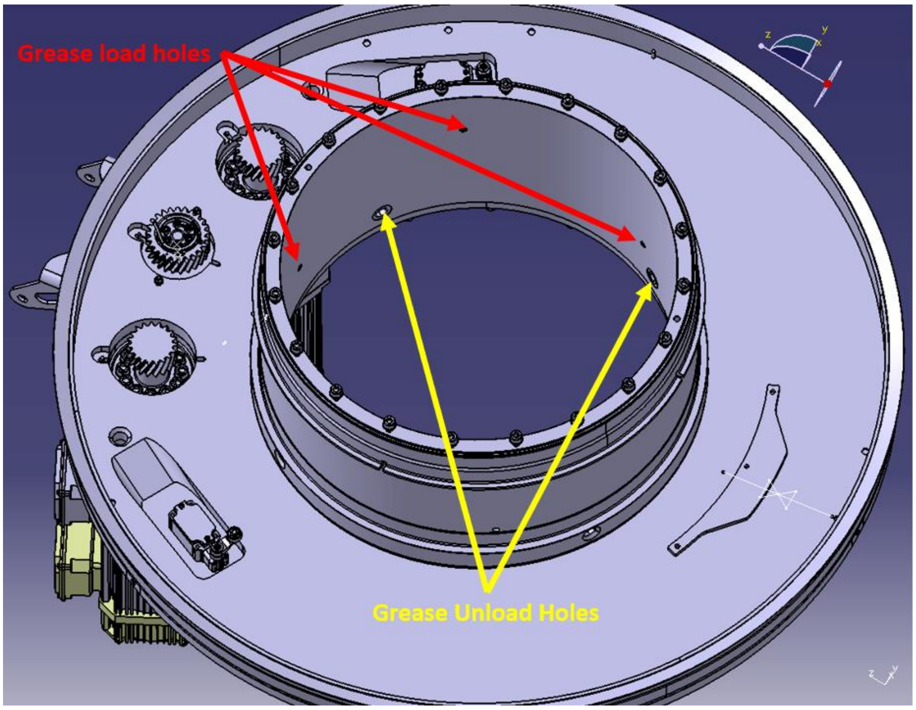


Figure 117 Feed Indexer Bearings lubrication 2

3.2.5.8 Indexer Actuators

Actuator sizing

Table 15 Actuator sizing design data

SIZING ACTUATORS		
Platform maximum rotating Speed	8.0	deg/s
Platform rotating Speed during tracking	8.0	deg/s
Platform maximum rotating acceleration	6.0	deg/s2
Platform rotating acceleration during tracking	3.0	deg/s2
Distance of Mount axis from FI axis	881.0	mm
Limit Maximum linear acceleration at mount level	10.00	m/s2
Maximum linear acceleration at mount level	**0.10**	**m/s2**
Angular total stroke	203.34	deg
Time for start & stop during tracking	5.33	sec
Angular stroke during start & stop	21.33	deg
Time stroke at constant speed	22.75	sec
Time for total stroke	**28.08**	**sec**
TRANSMISSION DATA		
Platform gear ratio	13.6	[-]
Gearbox gear ratio	110.0	[-]
Total transmission ratio	1,499.5	[-]
SINGLE COMPONENT INERTIAL DATA		
Platform rotating inertia (CAD data)	1,190.00	kg*m2
Platform rotating inertia max	1,322.22	kg*m2
Platform rotating inertia min	1,071.00	kg*m2
Platform gear efficency	0.95	[-]
Gearbox rotating inertia	2.23E-04	kg*m2
Gearbox mechanical efficiency	0.92	[-]
Motor rotating Inertia	1.92E-03	kg*m2
Brake rotating Inertia	2.28E-03	kg*m2

COMPONENT INERTIAL DATA AT PLATFORM LEVEL		
Platform rotating inertia (CAD data)	1,190.00	kg*m2
Platform rotating inertia max	1,322.22	kg*m2
Platform rotating inertia min	1,071.00	kg*m2
Gearbox rotating inertia	4.38E+02	kg*m2
Motor rotating Inertia	3.77E+03	kg*m2
Brake rotating Inertia	4.48E+03	kg*m2
Total system rotating inertia (max) at platform level - Corrected with gear ratio	**10,013.95**	**kg*m2**
LOAD DATA AT PLATFORM LEVEL		
Max Acceleration load	**1,048.7**	**Nm**
Tracking acceleration load	**524.3**	**Nm**
Friction loads (DTM-20Sep2017.jpg)	75.0	Nm
Friction loads (SAM -Bearings_Rev02.xlsx)	329.0	Nm
Used Friction loads	**329.0**	**Nm**
Max Unbalance	**413.0**	Nm
Platform maximum Total torque	**1,790.65**	**Nm**
Platform torque during tracking	**1,266.32**	**Nm**

LOAD DATA AT MOTOR LEVEL		
Total mechanical efficiency	0.874	[-]
Max Acceleration load	0.800	Nm
Tracking acceleration load	0.400	Nm
Friction loads	0.251	Nm
Unbalance	0.315	Nm
Additional safety torque (+80%)	1.093	Nm
Required maximum torque	**2.46**	**Nm**
Required torque during tracking	**2.06**	**Nm**
Number of motors	2	[-]
Motor maximum torque	**1.23**	**Nm**
Motor torque during tracking	**1.03**	**Nm**
Motor added torque to avoid backlash at SPF position (50% of the added torque of 0.48 Nm)	**0.24**	**Nm**
Motor maximum torque with backlash control	**1.47**	**Nm**
Motor maximum speed	**1,999**	**rpm**
Motor torque limiter setting to avoid Gears teeth damage	**2.60**	**Nm**

Two asynchronous servo motors drive via a planetary gear and pinion(s) to the gear rack the feed indexer rotating parts. Backlash is removed by operating the two motors with opposing torque.
The motor selected is Lenze, model MCA 14L20 S20P1 with resolver and holding brake. Its main characteristics are:

- M_n: 6.7 Nm
- N_n: 2000 rpm
- P_N: 1.4kW
- M_{Brake}: 12Nm

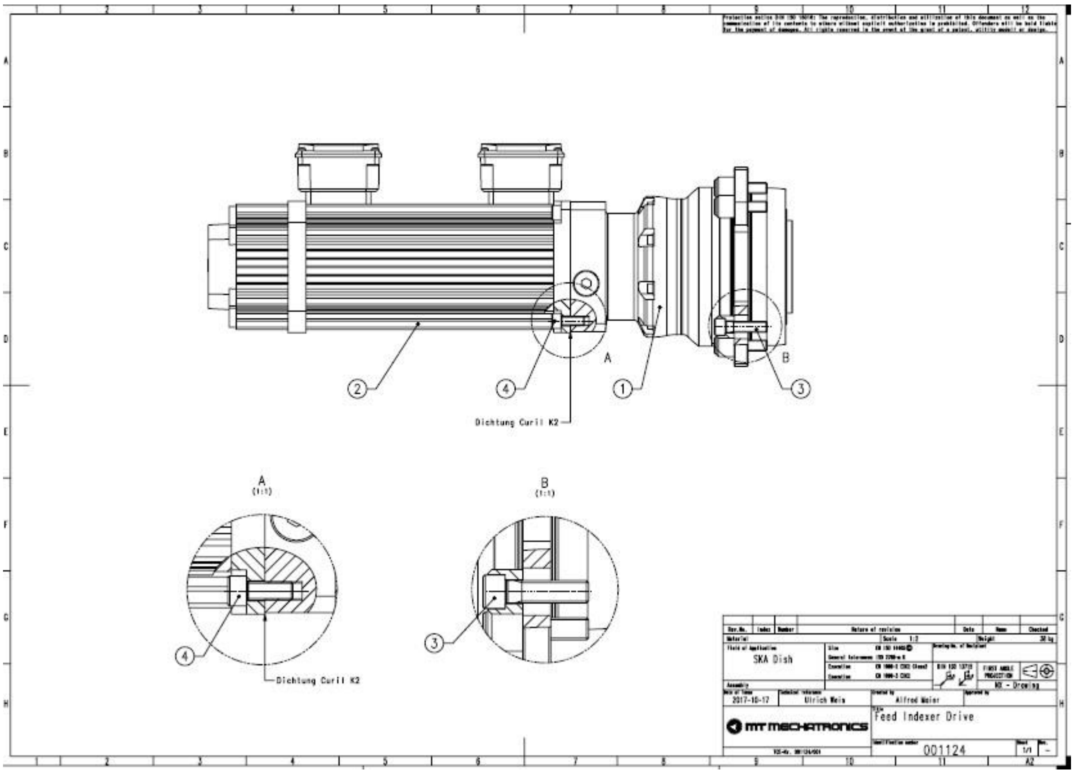
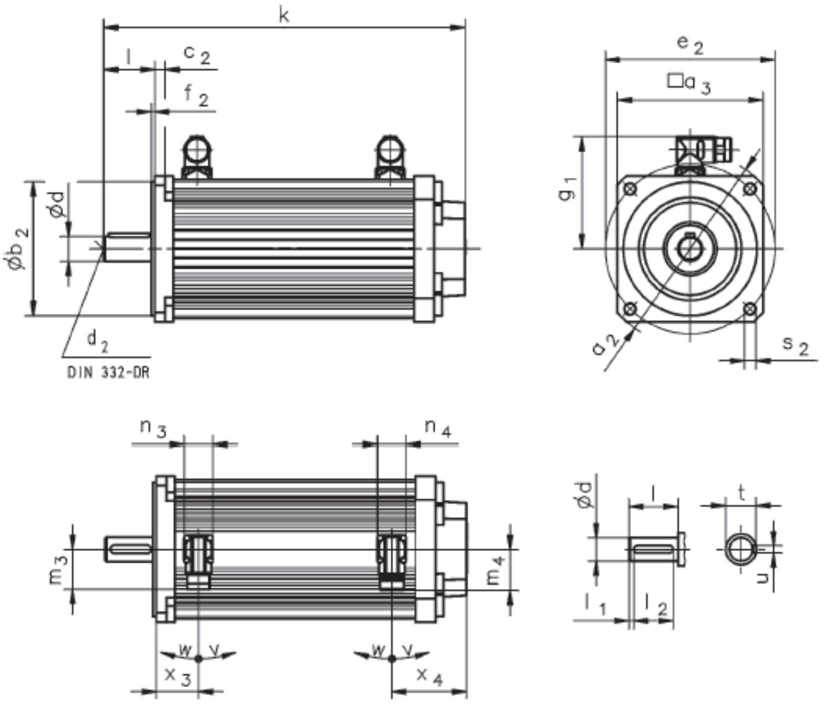


Figure 118 LENZE MCA14L20

In the following table the motors characteristics are summarized:

Table 16 Motor characteristics

Dimensions, self-ventilated



			MCA10I40	MCA13I41	MCA14L20	MCA17N23	MCA19S23	MCA21X25
					MCA14L41	MCA17N41	MCA19S42	MCA21X42
R□0 B0	k	[mm]	292	311	352	390	461	550
	x_3	[mm]	37	45	41	43	56	62
	x_4	[mm]	61	65		73		78
R□0 P□	k	[mm]	317	346	385	425	499	592
	x_3	[mm]	59	72	68	75	91	102
	x_4	[mm]	61	65		73		78
S□□ / E□□ / T20 / B0	k	[mm]	346	365	407	444	511	599
	x_3	[mm]	37	45	41	43	56	62
	x_4	[mm]	115	119	128	127	123	127
S□□ / E□□ / T20 / P□	k	[mm]	371	400	440	479	549	641
	x_3	[mm]	59	72	68	75	91	102
	x_4	[mm]	115	119	128	127	123	127

- Speed/angle sensor: RS0 / S□□ / E□□ / T20
- Brake: B0 / P□

Dimensions, self-ventilated

<table>
<tr><th></th><th>g_1</th><th>n_3</th><th>n_4</th><th>m_3</th><th>m_4</th><th>v</th><th>w</th></tr>
<tr><th></th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[°]</th><th>[°]</th></tr>
<tr><td>MCA10I40</td><td>90</td><td rowspan="6">28</td><td rowspan="10">28</td><td rowspan="6">40</td><td rowspan="10">40</td><td rowspan="10">195</td><td rowspan="10">80</td></tr>
<tr><td>MCA13I41</td><td>102</td></tr>
<tr><td>MCA14L20</td><td rowspan="2">109</td></tr>
<tr><td>MCA14L41</td></tr>
<tr><td>MCA17N23</td><td rowspan="2">118</td></tr>
<tr><td>MCA17N41</td></tr>
<tr><td>MCA19S23</td><td rowspan="2">151</td><td rowspan="4">40</td><td rowspan="4">71</td></tr>
<tr><td>MCA19S42</td></tr>
<tr><td>MCA21X25</td><td rowspan="2">162</td></tr>
<tr><td>MCA21X42</td></tr>
</table>

<table>
<tr><th></th><th>d</th><th>d_2</th><th>l</th><th>l_1</th><th>l_2</th><th>u</th><th>t</th></tr>
<tr><th></th><th>k6</th><th></th><th></th><th></th><th></th><th></th><th></th></tr>
<tr><th></th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th></tr>
<tr><td>MCA10</td><td>14</td><td>M5</td><td>30</td><td>2.5</td><td>25</td><td>5.0</td><td>16.0</td></tr>
<tr><td>MCA13</td><td>19</td><td>M6</td><td>40</td><td>2.0</td><td>36</td><td>6.0</td><td>21.5</td></tr>
<tr><td>MCA14</td><td rowspan="2">24</td><td rowspan="2">M8</td><td rowspan="2">50</td><td rowspan="4">5.0</td><td rowspan="2">40</td><td rowspan="3">8.0</td><td rowspan="2">27.0</td></tr>
<tr><td>MCA17</td></tr>
<tr><td>MCA19</td><td>28</td><td>M10</td><td>60</td><td>50</td><td>31.0</td></tr>
<tr><td>MCA21</td><td>38</td><td>M12</td><td>80</td><td>70</td><td>10.0</td><td>41.0</td></tr>
</table>

<table>
<tr><th></th><th>a_2</th><th>a_3</th><th>b_2</th><th>c_2</th><th>e_2</th><th>f_2</th><th>s_2</th></tr>
<tr><th></th><th></th><th></th><th>j6</th><th></th><th></th><th></th><th></th></tr>
<tr><th></th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th><th>[mm]</th></tr>
<tr><td rowspan="2">MCA10</td><td rowspan="2">120</td><td rowspan="2">102</td><td>80</td><td rowspan="2">8</td><td>100</td><td>3.0</td><td>7</td></tr>
<tr><td>70</td><td>85</td><td>2.5</td><td>M6</td></tr>
<tr><td rowspan="2">MCA13</td><td rowspan="2">160</td><td rowspan="2">130</td><td rowspan="2">110</td><td rowspan="2">9</td><td rowspan="2">130</td><td rowspan="6">3.5</td><td>9.0</td></tr>
<tr><td>M8</td></tr>
<tr><td rowspan="2">MCA14</td><td rowspan="2">188</td><td rowspan="2">142</td><td>130</td><td rowspan="2">10</td><td>165</td><td>11.0</td></tr>
<tr><td>110</td><td>130</td><td>M8</td></tr>
<tr><td rowspan="2">MCA17</td><td rowspan="2">200</td><td rowspan="2">165</td><td>130</td><td rowspan="2">12</td><td>165</td><td>11.0</td></tr>
<tr><td>110</td><td>130</td><td>M8</td></tr>
<tr><td rowspan="2">MCA19</td><td rowspan="3">250</td><td rowspan="2">192</td><td>180</td><td rowspan="3">11</td><td>215</td><td>4.0</td><td>13.0</td></tr>
<tr><td>110</td><td>130</td><td>3.5</td><td>M8</td></tr>
<tr><td rowspan="3">MCA21</td><td>214</td><td>180</td><td>215</td><td rowspan="2">4.0</td><td rowspan="2">13.0</td></tr>
<tr><td>300</td><td>250</td><td>230</td><td>12</td><td>265</td></tr>
<tr><td>250</td><td>214</td><td>110</td><td>11</td><td>130</td><td>3.5</td><td>M8</td></tr>
</table>

The selection has been done in function of the torque budget values that you can see in the following table:

Table 17 Indexer torque budget

Feed Indexer		
given values		**comments and formulas**
Velocity maximum	12.0 °/s	spec + margin
Velocity tracking	0.1 °/s	
Acceleration maximum	8.20 °/s²	e-stop
Acceleration tracking	0.10 °/s²	
Weight	2,000 kg	FE model incl. margin
Friction factor μ	0.0450	
Radius of rail r_{AZ}	0.3 m	design
Inertia max	1,778 kgm²	input SAM / 0.9
Inertia min	1,440 kgm²	input SAM * 0.9
Inertia of motor	0.00000 kgm²	DT5-5-10-RBO
Inertia of brake	0.00000 kgm²	incl. in motor
Unbalance	500 Nm	input SAM
Ratio motor/axes	1,238.9	i_{gear}=100, i_{pinion}=12.389
motors per axis	2.0	
calculated values axes		
Maximum acceleration load	254.4 Nm	$M_{acc,axis}$ = ($J_{mount,max}$+(J_{mot}*n_{mot}*i²) +(J_{brake}*n_{brake}*i²))*a_{max}*PI/180
Friction loads	3,981.6 Nm	$M_{fric,axis}$ = weight*μ_{fric}*9,81*$r_{rail,aver.}$ + 2*1.5Nm gear friction
Unbalance	500 Nm	input SAM
Total	**4,736.0 Nm**	$M_{total,axis}$ = $M_{acc,axis}$ + $M_{fric,axis}$ + $M_{wind,axis}$
Tracking acceleration load	3.1 Nm	$M_{acc,axis}$ = ($J_{mount,max}$+(J_{mot}*n_{mot}*i²) +(J_{brake}*n_{brake}*i²))*$a_{tracking}$*PI/180
Total during tracking	**4,484.7 Nm**	$M_{tracking,axis}$ = $M_{acc,axis}$ + $M_{fric,axis}$ + $M_{wind,axis}$
values motors side (div by gear ratio and 2 motors)		
Maximum acceleration load	0.1 Nm	Macc = $M_{acc,axis}$ / i / n_{mot}
Tracking acceleration load	0.0 Nm	Macc = $M_{acc,axis}$ / i / n_{mot}
Friction loads	1.6 Nm	Mfric = fric_load / i / n_{mot}
Unbalance	0.2 Nm	Mwind = wind_load / i / n_{mot}
add. Safety factor torque (1.8)	1.5 Nm	Msafety = (Macc + Mfric + Mwind) * 1,8
Total requiered torque	**3.4 Nm**	M_{acc} + M_{fric} + M_{wind} + M_{safety}
Motor speed	2,477.80 rpm	
Motor speed tracking	20.65 rpm	

3.2.5.9 Rotative Encoder

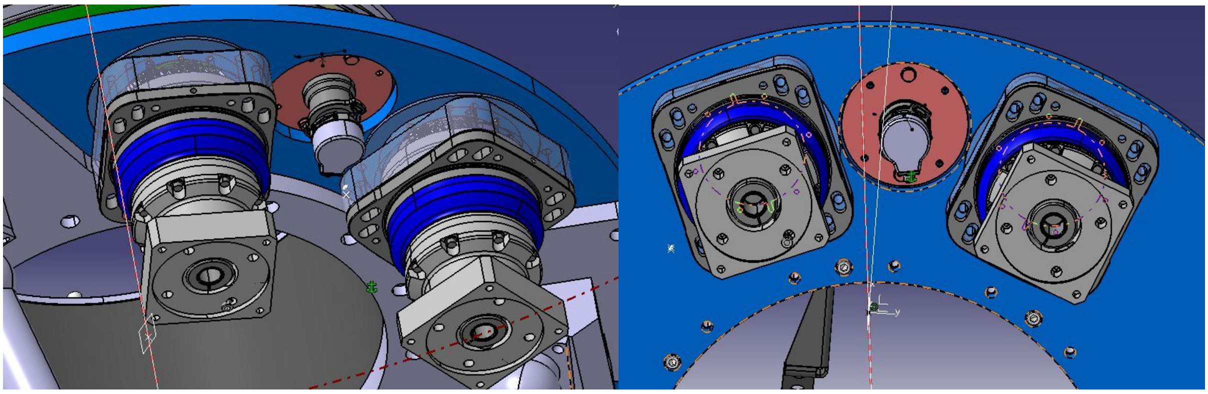


Figure 119 Feed indexer encoder

A pre-tensed gear assembly will be installed, with a pinion on the encoder shaft. The ratio is chosen to be 1/12 of the main toothed gear diameter to the encoder axis.
Enclosed by an EMI housing, the concept is identical to the one for the main axes with one exception. The limit switches are mounted outside the FI I/O Unit, they are connected through different cables and EMI filters to the electronics inside the I/O Unit (enclosure not shown).

Heidenhaim EQN437		
Encoder Absolute Accuracy	20,00	arcsec
Gear Ratio	14,11	[]
Accuracy at Main Wheel Level	1,42	arcsec
Focus distance from rotation axis	1400	mm
Accuracy Resolution at focus level	9,62E-03	mm
Gear Module	3.00	mm
Pinion Diameter	54.00	mm
Pinion Teeth	18	
Wheel Diameter	762.00	mm
Wheel Teeth	254	
Distance between axes	408	mm
Gear Ratio	14.11	-

Figure 120 Feed indexer encoder, Heidenhain EQN437

The selection of the encoder type was performed in order to satisfy the positioning accuracy required to position the feeds into the focus of the optical path. A sub-system specification for the feed indexer is available defining the accuracy required by the feed indexer itself (see [RD7]). The feed indexer encoder error can be translated to an encoder accuracy of 44.2” considering the radius of the feed to the feed indexers axis of rotation. The additional ratio due to the pre-tensed gearwheel reduces the accuracy requirement of the encoder itself. The encoder assembly error contribution is sufficient to bring the total error budget within the limit of the indexing repeatability (0,04 mm).

The accuracy requirements are fulfilled by the selected encoder type EQN437. The datasheet and further information are provided below.

	Absolute					
	Singleturn			**Multiturn**		
	ECN 425	**ECN 413**		**EQN 437**	**EQN 425**	
Interface*	EnDat 2.2	EnDat 2.2	SSI	EnDat 2.2	EnDat 2.2	SSI
Ordering designation	EnDat22	EnDat01	SSI39r1	EnDat22	EnDat01	SSI41r1
Positions per revolution	33554432 (25 bits)	8192 (13 bits)		33554432 (25 bits)	8192 (13 bits)	
Revolutions	–			4096		
Code	Pure binary		Gray	Pure binary		Gray
Elec. permissible speed Deviations[1]	≤ 12000 rpm for continuous position value	*512 lines:* ≤ 5000/12000 rpm ± 1 LSB/± 100 LSB *2048 lines:* ≤ 1500/12000 rpm ± 1 LSB/± 50 LSB	≤ 12000 rpm ± 12 LSB	≤ 12000 rpm for continuous position value	*512 lines:* ≤ 5000/10000 rpm ± 1 LSB/± 100 LSB *2048 lines:* ≤ 1500/10000 rpm ± 1 LSB/± 50 LSB	≤ 12000 rpm ± 12 LSB
Calculation time t_{cal} Clock frequency	≤ 7 µs ≤ 8 MHz	≤ 9 µs ≤ 2 MHz	≤ 5 µs –	≤ 7 µs ≤ 8 MHz	≤ 9 µs ≤ 2 MHz	≤ 5 µs –
Incremental signals	Without	∼ 1 V_{PP}[2]		Without	∼ 1 V_{PP}[2]	
Line counts*	–	**512** 2048	**512**	–	**512** 2048	**512**
Cutoff frequency –3 dB Output frequency	– –	*512 lines:* ≥ 130 kHz; *2048 lines:* ≥ 400 kHz –		– –	*512 lines:* ≥ 130 kHz; *2048 lines:* ≥ 400 kHz –	
System accuracy	± 20"	*512 lines:* ± 60"; *2048 lines:* ± 20"		± 20"	*512 lines:* ± 60"; *2048 lines:* ± 20"	
Electrical connection*	• **Flange socket** M12, radial • Cable 1 m, with M12 coupling	• **Flange socket** M23, radial • Cable 1 m, with M23 coupling or without connecting element		• **Flange socket** M12, radial • Cable 1 m, with M12 coupling	• **Flange socket** M23, radial • Cable 1 m, with M23 coupling or without connecting element	
Voltage supply*	**3.6 V to 14 V DC**		**4.75 V DC to 30 V**	**3.6 V to 14 V DC**	**3.6 V to 14 V DC**	**4.75 V DC to 30 V**
Power consumption (maximum)	*3.6 V:* ≤ 0.6 W *14 V:* ≤ 0.7 W		*5 V:* ≤ 0.8 W *10 V:* ≤ 0.65 W *30 V:* ≤ 1 W	*3.6 V:* ≤ 0.7 W *14 V:* ≤ 0.8 W		*5 V:* ≤ 0.95 W *10 V:* ≤ 0.75 W *30 V:* ≤ 1.1 W
Current consumption (typical; without load)	*5 V:* 85 mA		*5 V:* 90 mA *24 V:* 24 mA	*5 V:* 105 mA		*5 V:* 120 mA *24 V:* 28 mA
Shaft*	**Blind hollow shaft** or **hollow through shaft; D = 8 mm** or **D = 12 mm**					
Mech. permiss. speed n[3]	≤ 6000 rpm/≤ 12000 rpm[4]					
Starting torque At 20 °C Below –20 °C	*Blind hollow shaft:* ≤ 0.01 Nm; *Hollow through shaft:* ≤ 0.025 Nm (for IP66: ≤ 0.075 Nm) ≤ 1 Nm					
Moment of inertia of rotor	≤ 4.3 · 10^{-6} kgm^2					
Permissible axial motion of measured shaft	± 1 mm					
Vibration 55 to 2000 Hz **Shock** 6 ms	≤ 300 m/s^2; *flange socket version:* ≤ 150 m/s^2 (EN 60068-2-6); higher values upon request ≤ 1000 m/s^2 (EN 60068-2-27)					
Max. operating temp.[3]	100 °C					
Min. operating temp.	*Flange socket or fixed cable:* –40 °C; *moving cable:* –10 °C					
Protection EN 60 529	*At housing:* IP67 (IP66 for hollow through shaft) *At shaft inlet:* IP 64 (for D = 12 mm, IP66 available on request)					
Mass	≈ 0.3 kg					
Valid for ID	683644-xx	1065932-xx	1132405-xx	683646-xx	1109258-xx	1132407-xx

Bold: This preferred version is available on short notice.
* Please select when ordering
1) Velocity-dependent deviations between the absolute value and incremental signal
2) Restricted tolerances: Signal amplitude 0.8 to 1.2 V_{PP}
3) For the relationship between the operating temperature and the shaft speed or supply voltage, see *General Mechanical Information*
4) With two shaft clamps (only for hollow through shaft)

Figure 121 Encoder Data Sheet

Gears

In order to select the right gears to use, a depth study has been carried out

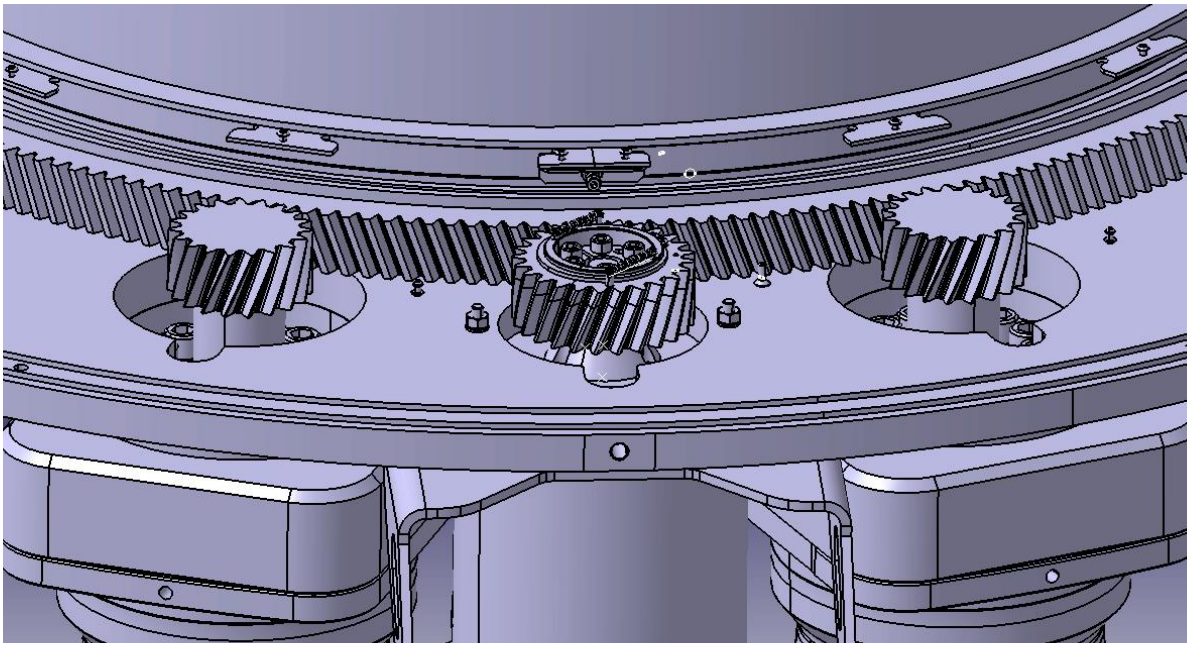


Figure 122 Gears Design configuration

Following table summarize the design data for the motor gears and the encoder gear.

Table 18 Motor Gears design data

GEOMETRIC DATA - MOTOR GEAR REVISED BY CEBA 27 june 2017			
	SYMBOL	MAIN WHEEL	PINION
		Helical Gear	Helical Gear
Number of Teeth	Z	259	19
Module (mm)	m		
Normal Module (mm)	m_n	3.00	
Radial Module (mm)	m_t	3.1925	
Standard Pressure Angle (°)	α		
Normal Pressure Angle (°)	α_n	20.00	
Radial Pressure Angle (°)	α_t	21.173	
Helix Angle (°)	β	20.0	
Gear width (mm)	b	30	32
Pitch Diameter (mm)	D	826.87	60.66
Base Diameter (mm)	D_b	771.049	56.56
Circular Pitch (mm)	p		
Normal circular Pitch (mm)	p	9.42	
Radial circular Pitch (mm)	p	10.03	
Standard Center Distance (mm)	a	443.76	

Coefficient of Profile Shift =Correction(mm)/module	X_1, X_2		
Normal Coefficient of Profile Shift =Correction(mm)/normal module	X_{n1}, X_{n2}	0.000025	0.416400
Inv α	Inv α		
Inv α_w	Inv α_w		
Inv α_t	Inv α_t	0.017793	
Inv α_n	Inv α_n	0.014904	
Inv α_{wt}	Inv α_{wt}	0.018884	
Working pressure angle (°)	α_w		
Working pressure angle (°)	α_{wt}	21.5806	
Center Distance Increment Factor	Y	0.4126	
Working Center Distance (mm)	a_x	445.000	
Working Pitch Diameter (mm)	D_w	829.173	60.83
Addendum (mm)	h_a	2.989	4.238
Tooth Whole Depth (mm)	h	6.739	
Outside Diameter (mm)	D_a	832.84	69.13
Root Diameter (mm)	D_f	819.37	55.66
Radial Contact Ratio	ε_α	1.46	
Axial Contact Ratio	ε_β	1.09	
Total Contact Ratio	ε_γ	2.54	
Speed ratio	i	13.63	

Table 19 Encoder Gear design data

GEOMETRIC DATA - ENCODER GEAR REVISED BY CEBA 27 june 2017			
	SYMBOL	MAIN WHEEL	PINION
		Helical Gear	Helical Gear
Number of Teeth	Z	259	25
Module (mm)	m		
Normal Module (mm)	m_n	3.00	
Radial Module (mm)	m_t	3.1925	
Standard Pressure Angle (°)	α		
Normal Pressure Angle (°)	α_n	20.00	
Radial Pressure Angle (°)	α_t	21.173	
Helix Angle (°)	β	20.0	
Gear width (mm)	b	23	
Pitch Diameter (mm)	D	826.87	79.81
Base Diameter (mm)	D_b	771.05	74.43
Circular Pitch (mm)	p		
Normal circular Pitch (mm)	p	9.42	
Radial circular Pitch (mm)	p	10.03	
Standard Center Distance (mm)	a	453.34	
Coefficient of Profile Shift =Correction(mm)/module	X_1,X_2		
Normal Coefficient of Profile Shift =Correction(mm)/normal module	X_{n1},X_{n2}	0.000025	0.221000
Inv α	Inv α		
Inv α_w	Inv α_w		
Inv α_t	Inv α_t	0.017793	
Inv α_n	Inv α_n	0.014904	
Inv α_{wt}	Inv α_{wt}	0.018360	
Working pressure angle (°)	α_w		
Working pressure angle (°)	α_{wt}	21.3868	
Center Distance Increment Factor		0.2200	
Working Center Distance (mm)	a_x	454.000	
Working Pitch Diameter (mm)	D_w	828.07	79.93
Addendum (mm)	h_a	2.997	3.660
Tooth Whole Depth (mm)	h	6.747	
Outside Diameter (mm)	D_a	832.86	87.13
Root Diameter (mm)	D_f	819.37	73.64
Radial Contact Ratio	ε_α	1.55	
Axial Contact Ratio	ε_β	0.83	
Total Contact Ratio	ε_γ	2.39	
Speed ratio	i	10.36	

A Gears Fatigue analysis has been done too:

Table 20 Gears Fatigue analysis

LOAD DATA ON PLATFORM GEAR Used for Gear design			
Max Acceleration load (only platform)	138.5	Nm	
Tracking acceleration load (only platform)	69.2	Nm	
Friction loads (only platform)	329.0	Nm	
Unbalance	413.0	Nm	
Additional safety torque (80%)	704.4	Nm	
Max torque on platform	1,584.8	Nm	
Main gear efficency	0.95	[-]	
Max torque required to rotate platform	1,668.22	Nm	
Number of motors	2.0	[-]	
Main gear Maximum torque required x Motor	834.1	Nm	
Additional torque to avoid Backlash (safety factor = 1.5) (50% for each motor)	309.7	Nm	
Total Torque x motor (at platform level)	1,143.9	Nm	
LOADING DATA FOR HELICAL GEARS		MAIN WHEEL	
Max operating torque on Wheel due to the driving motor	834.1	Nm	From Motors_Torque_Rev 4_00.xlsx
Max operating torque on Wheel due to the reaction motor	309.7	Nm	
Max operating Circular Force (Fu)	2,758.9	N	
Max operating Axial Thrust force due to the driving motor	1,004.2	N	
Max operating Radial force due the driving motor	1,068.6	N	

STRESS CALCULATION FOR HELICAL GEAR - JGMA 401-01 Rules			
	SYMBOL	MAIN WHEEL	PINION
		Helical Gear	Helical Gear
Tangential Force (F1) [N] Normal to tooth	F_1	2,936.0	2,936.0
Corrected Gear Blank [mm]	b	30	32
Equivalent Spur Gear Number of Te	Z_V	312.1	22.9
Normal Coefficient of Profile Shift =Correction(mm)/normal module	X_{n1}, X_{n2}	0.00	0.42
Tooth Profile Factor (v. Fig. 17-1)	Y_F	2.13	2.23
Radial Contact Ratio	ε_α	1.46	
Load Distribution Factor	$Y\varepsilon$	0.69	
Helix Angle Factor	Y_β	0.83	
Life Factor (safety assumption)	K_L	1.20	1.20
Dimension Factor of Root Stress (generally assumed)	K_{FX}	1.00	1.00
Platform rotation speed [rad/s]		0.14	
Tangential Speed at Pitch Line [m/s]		0.06	
Dynamic Load Factor (safety assum	K_V	1.00	
Overload Factor	K_0	1.00	
Safety Factor for Bending Failure	S_F	1.2	1.2
Gear Material		AISI 304 EN 1.4307	AISI 304 EN 1.4307
Tensile Strenght [Mpa]		505.0	505.00
σf lim [Mpa]		172.1	172.1
Correction for Bi-directional load		0.67	0.67
Used σf lim [Mpa]		114.76	114.76
Ft lim [N]		8467.88	8627.37
Used F_t [N]		2935.95	2935.95
Torque limit at platform level [Nm]		3,298.9	3,361.1
Total transmission ratio		1,449.5	
Total mechanical efficiency		0.874	
Torque limit at motor level [Nm]		2.6	2.7
Motor torque limiter setting [Nm]		**2.6**	

3.2.5.10 Dust & EMC Protection

Since the Feed Indexer will have to operate outdoor and in specific environmental conditions, there are some important elements which need to be protected. Specifically, three cover have been designed and produced. Two of them (upper cover and lower cover) have been designed to protect gears, pinions, limits switches and encoder mainly against water and dust.

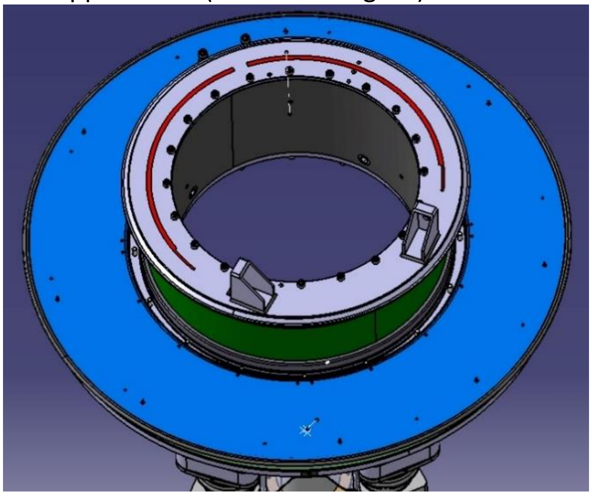
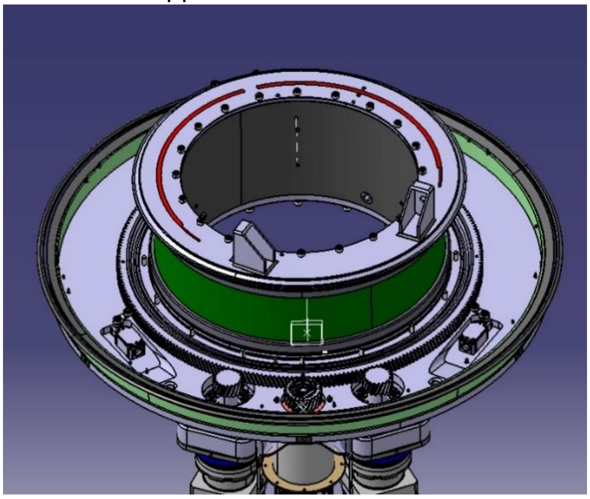
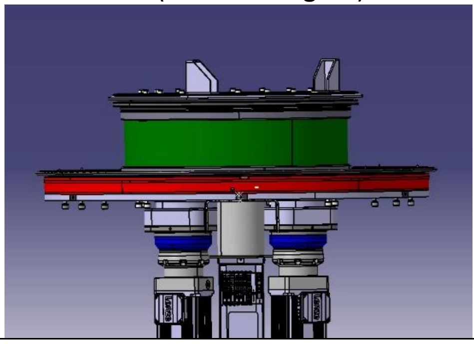
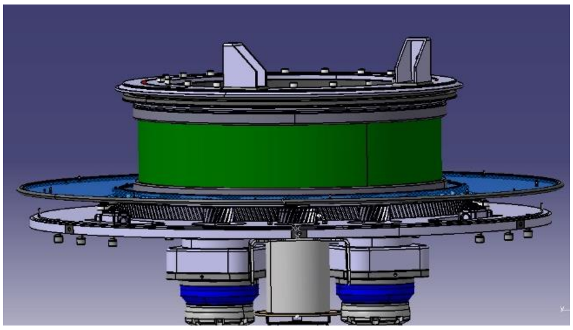
<table>
<tr><th colspan="2">UPPER COVER</th></tr>
<tr><td>Upper cover (blue in the figure) Installed:
</td><td>Upper Cover uninstalled:
</td></tr>
<tr><th colspan="2">LOWER COVER</th></tr>
<tr><td>Lower cover (red in the figure) installed
</td><td>Lowe cover uninstalled
</td></tr>
<tr><td colspan="2">Picture of the lower cover taken during the rain tests
</td></tr>
</table>

Figure 123 FI covers

The third cover which is the FI IO UNIT has a dual function: it protects the encoder and electronical components from dust and water, but at the same time it has to protect the telescope from the Electromagnetic and Radio interferences generated by the encoder and electronical components in order to ensure the compliance with the EMI RFI requirements. Below there is a photo of the FI IO Unit.

The FI it is divided in two parts, as we can see in the second figure below, this is because this way it is easier to maintain the electronic components inside the box.

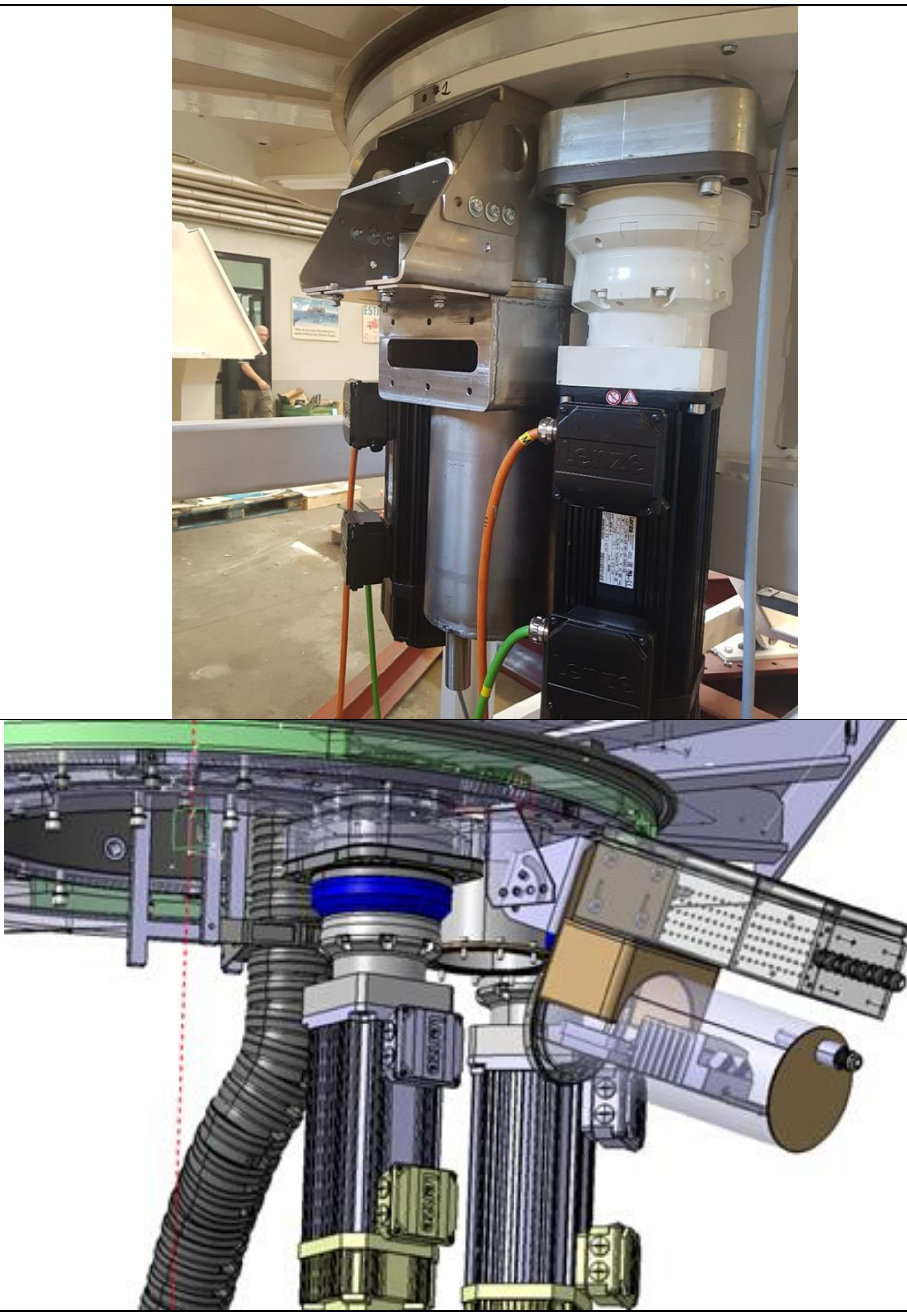


Figure 124 FI IO Unit

In order to be sure that the FI IO Unit is able to shield the Electromagnetic and Radio interferences two important components have been chosen:

- **EMI flat gasket (ES electronic service), Cho-seal 1285 - It is a gasket 1.57 mm thick positioned between the two box parts**

Figure 125 EMI Flat Gasket

- **EMI-RFI Spring Seal (BALSEAL) - It is a spring installed on the encoder shaft to ensure the EMI/RFI shielding. Specifically, the one installed on the Feed Indexer encoder has the following characteristics.**

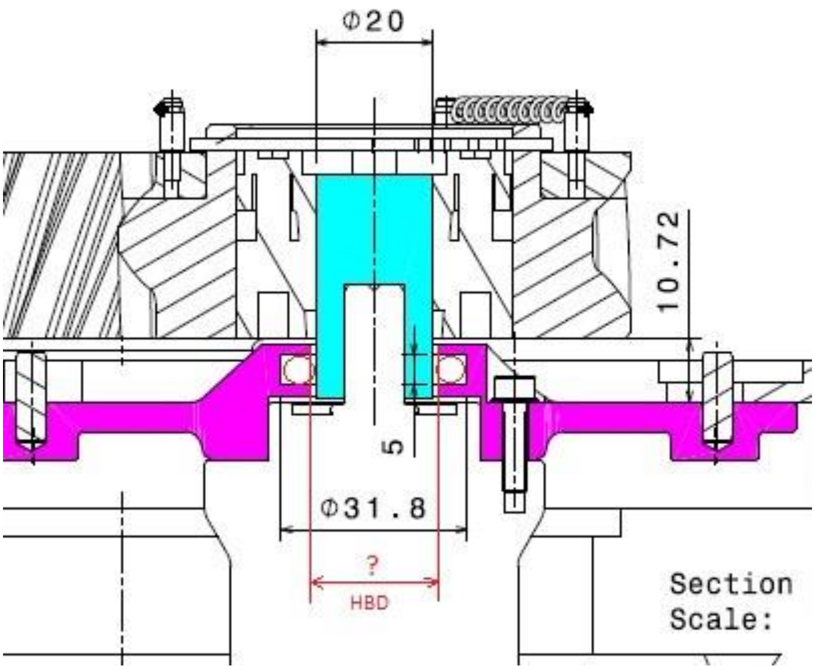


Figure 126 EMI-RFI spring installation

Figure 127 EMI-RFI Spring Seal

3.2.5.11 Limit switches & Hard Stops

Final limits and pre-limits based on hardwired limit switches is provided outside the observing range for Indexer rotations. Their positions are chosen in order to stop the Platform before the final limit if it encounters the pre-limit moving at its maximum velocity.

<u>Limit switches:</u>
In the figures below the limit switches installed on the Feed Indexer are shown.
Specifically, the two limit switches activation angles are -100,9° & 104,3°

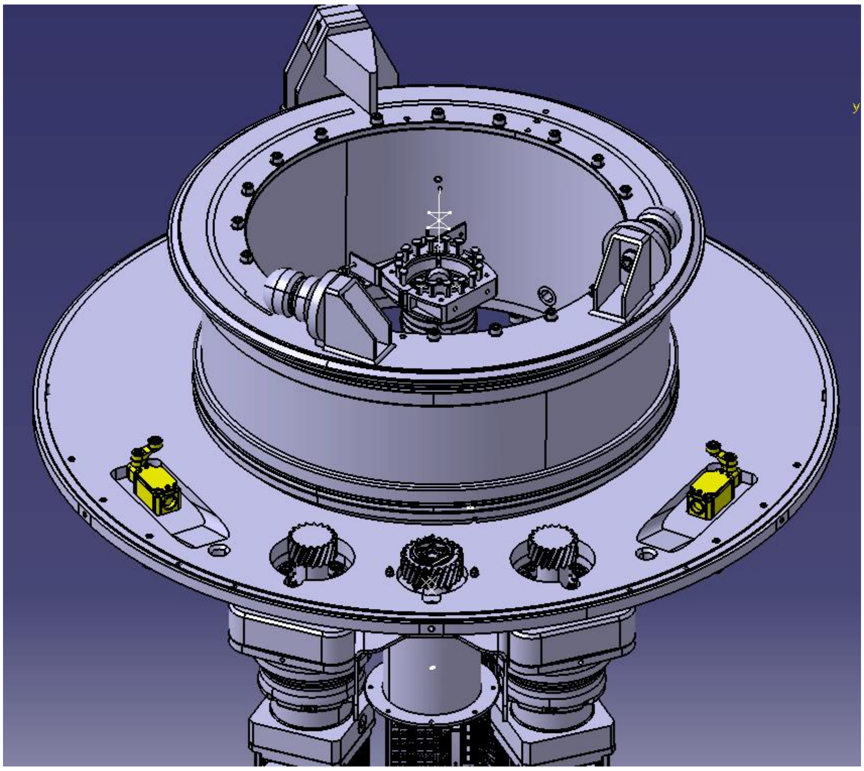


Figure 128 Limit switches

Hard stops:

Below the two hard stops installed on the Feed Indexer are shown

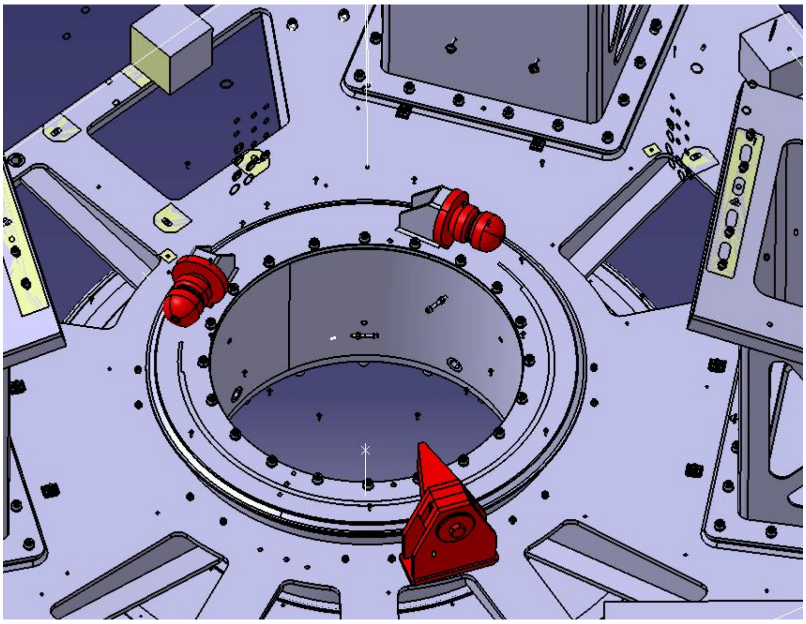


Figure 129 Hard stops position

The Hard stops are intended specifically to handle conditions when:

- either one of the actuator drive shaft/gear fails
- either one of the motor brakes fails
- the limit switch or safety circuit fails.

Engaging angles are:

- -112,1°
- 115,5°

Table 21 Hard Stops design

SHOCK ADSORBER DESIGN		
Total system rotating inertia (max) at platform level - Corrected with gear ratio	10,013.9	kg*m2
Platform maximum rotating Speed	8.0	deg/s
Platform maximum rotating Speed	0.140	rad/s
Initial Kinetic Energy	97.6	J
Shock Adsorber Type	PHE030-810645HE	
Shock adsorber axis distance	0.35	m
Shock Adsorber Stroke	47.6	mm
Max Shock Adsorber Force	6,181.8	N
Max Shock Adsorber Deceleration Torque	2,163.6	Nm
Max Platform Angular Deceleration	0.22	rad/s2
Mount axis distance	0.88	m
Max deceleration at mount level	0.19	m/s2
Unbalance (CoG in the worst position)	121.0	Nm
Load on shock adsorber due to unbalance	345.8	N
Total Force on Shock adsorber	6,527.6	N

Energy (Joule)	Stroke (mm)	Reaction Force(mm)	Max Energy (Joule)	Code
31	30	190	95	810644HE
100	50	580	300	810645HE
110	45	600	330	810666HE
180	67	750	540	810642HE
350	75	1 250	1 050	810653HE
360	65	1 400	1 100	810655HE
400	85	1 500	1 200	810669HE
300	70	900	-	810784HE
600	75	1 625	-	810775HE
1 050	90	2 375	-	810776HE
2 500	90	5 500	-	810733HE/60HE
7 100	150	11 000	-	810732HE/60HE
9 500	200	9 500	-	810731HE/60HE
13 000	130	18 000	-	810732HE/75HE
17 500	175	19 000	-	810731HE/75HE
21 000	200	25 000	-	810735HE/60HE
29 000	250	35 000	-	810734HE/60HE
41 000	200	70 000	-	810735HE/75HE
50 000	250	55 000	-	810734HE/75HE

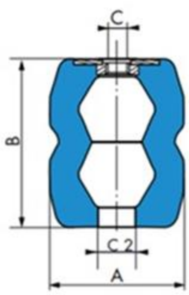


Fig. 1

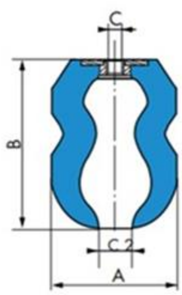


Fig. 2

Code	Fig.	Rubber Code	Ø A (mm)	B (mm)	C	Ø C1 (mm)	Ø C2 (mm)	Ø D (mm)	ØA Under load
810642HE	1	810022HE	85	120	M16	20	30	-	114
810644HE	1	810004HE	55	55	M10	14	14	-	72
810645HE	2	810035HE	66	93	M16	20	14	-	100
810653HE	1	810023HE	100	130	M16	20	30	-	140
810655HE	1	810025HE	110	132	M16	20	30	-	142
810666HE	2	810046HE	76	90	M16	20	14	-	98
810669HE	2	810029HE	110	150	M16	20	30	-	155
810731HE	3	-	250	400	6 x M24	70	70	150	360
810732HE	3	-	250	315	6 x M24	70	70	150	380
810733HE	3	-	250	230	6 x M24	70	70	150	370
810734HE	3	-	350	500	8 x M24	85	85	196	445
810735HE	3	-	350	395	8 x M24	85	85	196	500
810775HE	1	810015HE	155	150	M16	25	30	-	202
810776HE	1	810016HE	188	180	M24	40	40	-	256
810784HE	1	810014HE	125	140	M16	30	25	-	168

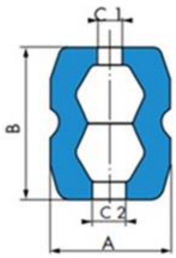
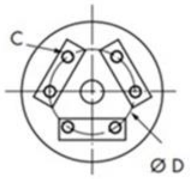
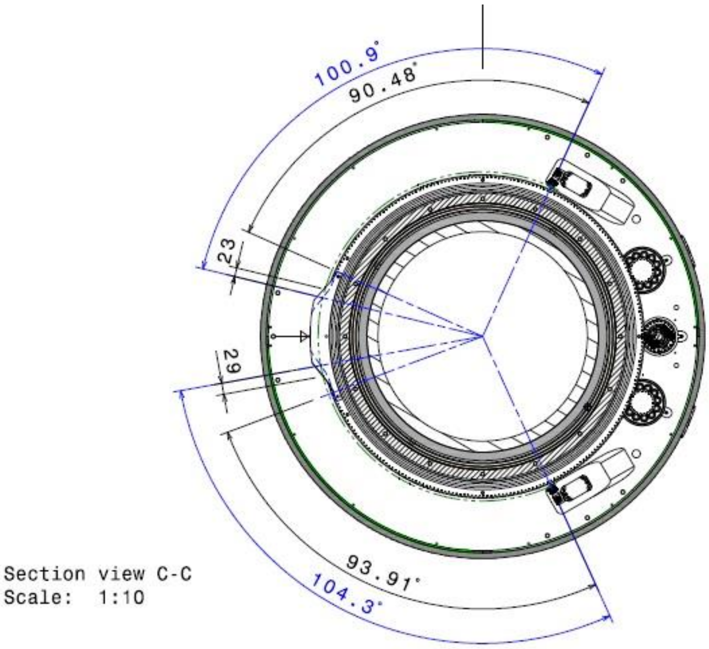


Fig. 3



In the figure below it is possible to see the position of the Limit switches and Hard stops:



Limit switches:	-100.9° & 104.3°
Stop buffer start engaging:	-112.1 & 115.5

Figure 130 Hard stops & Limit switches position

3.2.5.12 Feed Indexer Ray Tracing & keep out zones

The whole feed indexer, including the feeds, does not cross the optical path since no shadow enters into the convergent/divergent cones.

The ray tracing analysis has been performed in the PDR phase: no significant changes on mechanical configuration have been applied after PDR.

3.2.5.13 Equipment for Testing and Assembly

In order to carry out the tests, devices and structures that allow the simulation of the actual operation of the feed are needed.
In factory, tests and regulation have been carried out by using “dummy” structures which simulate the SPFs and other payloads and the antenna structure.

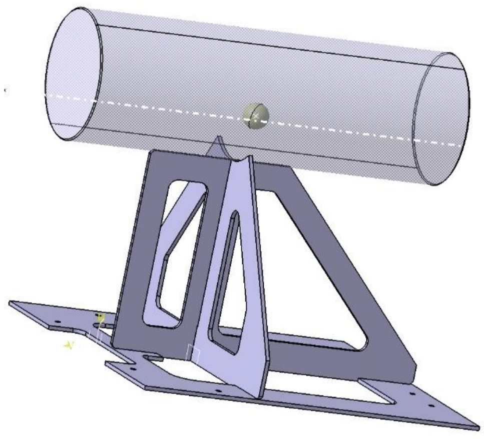
<u>Dummy Masses (SKA-MPI FAC)</u>

Each dummy mass assembly consists in one interface plate and cylindrical dummy weights. The size of the dummy weights and their location on the interface plates define the center of gravity of the dummy mass, which in turn should be equal to the CG of the actual component. The interface plate dimensions are equal to the interface dimensions of the actual component. The connection between the dummy interface plate and the FI is a copy of the connection between the actual component and the FI.

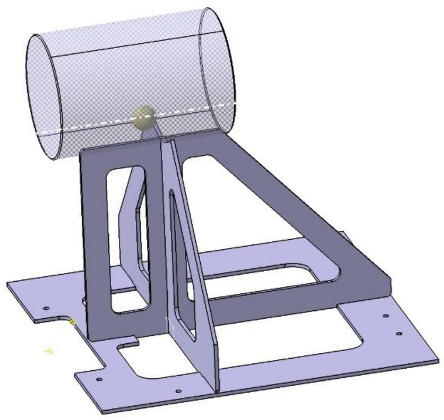
The table below shows the dummy masses and their relative weights.

Table 22 Dummy masses

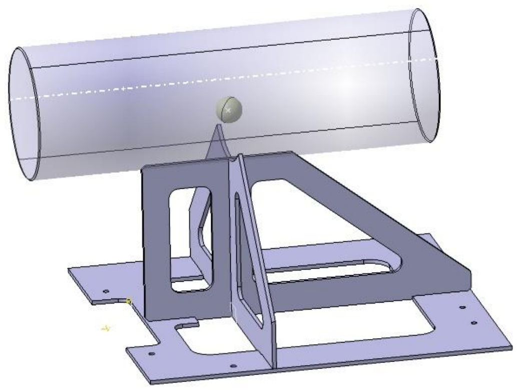
Feed indexer/ dummy	Component Name	Weight [kg]
dummy mass 1	SPF Band 1	165
dummy mass 2	SPF Band 2	85
dummy mass 3	SPF Band 345	160
dummy mass 4	SPFRx Sampler 123	30
dummy mass 5	SPFRx Sampler 45	30
dummy mass 6	Vacuum pump	50
dummy mass 7	Feed Indexer Fibre Routing Panel	12
dummy mass 8	FI Power Distribution Panel	7
TOTAL		539



dummy feed 1



dummy feed 2



dummy feed 345

Figure 131 Dummy masses (SPF’s)

Support Structure

In order to perform the feed indexer performance tests within the entire elevation range, it is required to provide a support structure that: supports the FI assembly weight, allows to change the structure elevation in the range of 0° - 75°, and allows to verify the FI indexing functionality.

The concept design is kept as simple and stable as possible. The concept consists in a lever structure, whose fulcrum is located close to the CG of the FI. The structure is realized by two bearings and a lifting frame, operated by a factory crane.

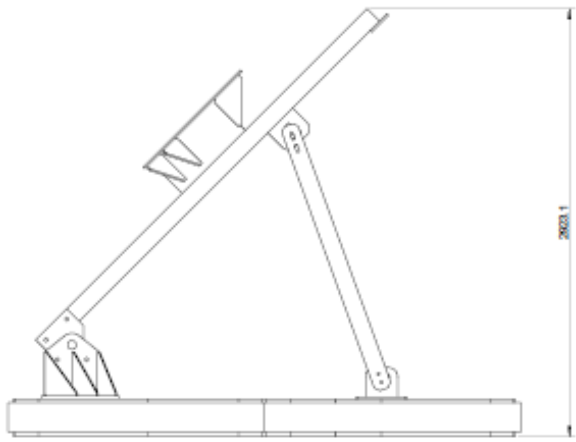
The overall support structure consists in the following components (figure…).

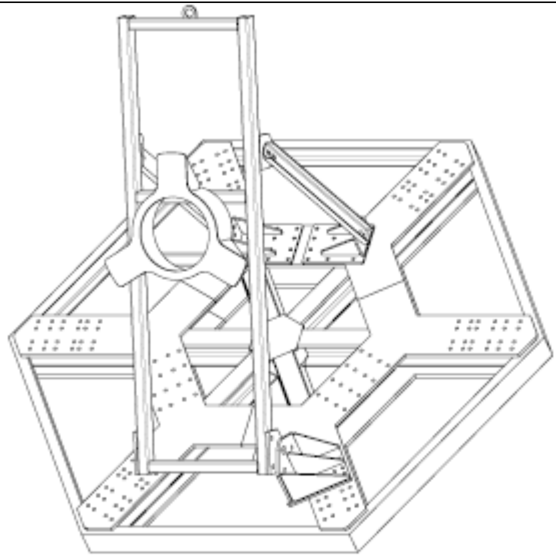
1. supporting plate,
2. interface cylinder/flange,
3. lifting frame assembly,
4. bearing assembly,
5. basement assembly.

The basement assembly consists in a basement plate and in a structure underneath the plate. This structure pushes out in a triangular shape beyond of the FI assembly, in order to support the assembly till the maximum elevation angle.

Figure 132 Supporting Structure

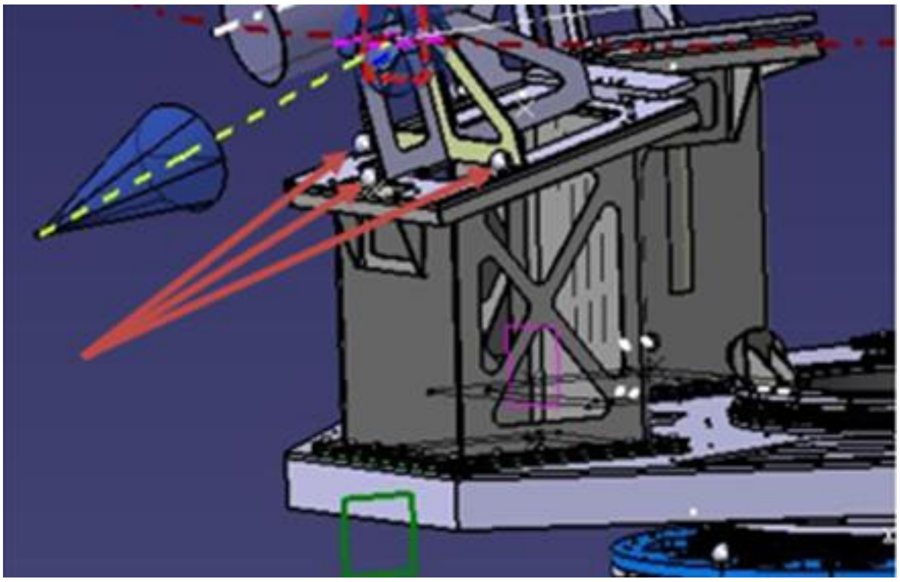
To screw the FI on the supporting plate, the FI could be lifted with a hoist and aligned to the plate.





Factory preliminary testing and verification, verification methodology, facilities and equipment

In order to carry out the physical geometry tests a “Leica Absolute Tracker AT403” will be used. This tool is characterized by a precision of 15 µm, it means that it is able to detect a displacement of 15 µm. It is used together with 3 “ball reference points” positioned on the feeds mount and 4 “ball reference points” positioned on the interface flange between the Feed Indexer and the support structure.



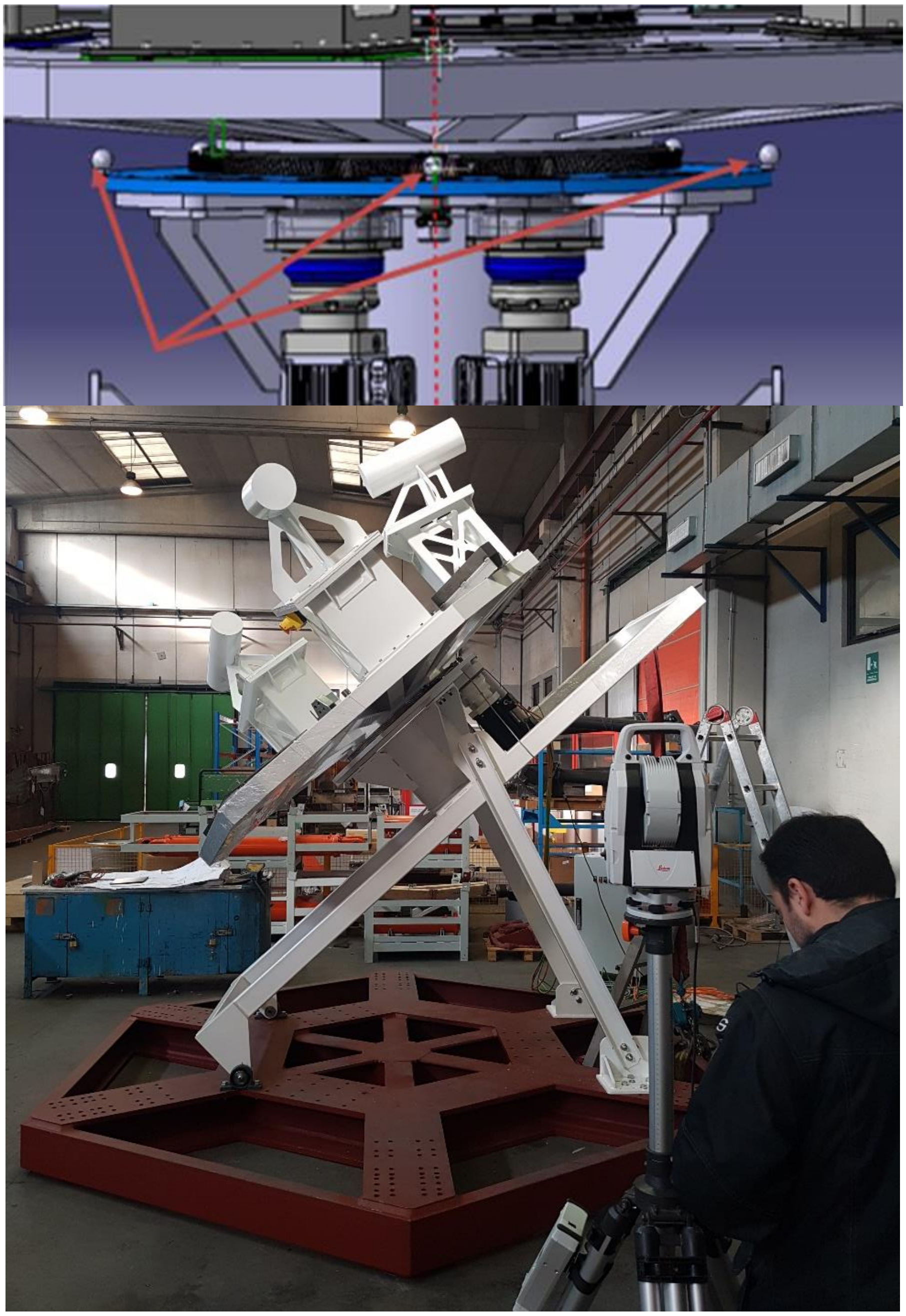


Figure 133 FI factory tests facility

3.2.5.14 Preliminary Packaging and Transportation Plan

The goal is to install the first 133 antennas and the subsequent SKA 2 array according to the following program:

- The two prototype antennas have been installed in Shijiazhuang, Hebei, China, and Karoo Desert South Africa, in 2018
- The first 133 antennas will be installed into the Karoo desert area, north of Cape Town, South Africa, in 5 years;
- The subsequent antennas will be installed again in South Africa and Australia.

The handling and transportation of Feed Indexer must be as safe as needed by equipment mechanical fragility ad cost-effective at the same time.

In order to minimize the transport costs, the best solution is to rent reusable containers and available one-way transport services from Manufacturer to Final User site. The shipping agents will take care of picking up the packaged Feed Indexer at Manufacturing Factory, of transporting the loaded container to nearest departure harbor, of delivering it to Final User for integration and of bringing back the empty container at nearest destination harbor for whatever future needs.

In order to ensure the required mechanical protection and safety for Feed Indexer and handling personnel, a special pallet is required to fasten almost rigidly the Feed Indexer each other and to the housing container as well. The Feed Indexer Manufacturer is in charge of packaging it on a proper transport pallet and of loading it into the container by an own fork-lift truck.

The shipping agent is in charge of all one-way transport phases from Manufacturer to Final User site by road and sea. The Feed Indexer Final User is in charge of unloading it from the container by an own fork-lift truck and of un-packaging it for integration.

The most common reusable containers for road and sea transport are the ISO 668 standard ones. For this project, the 20ft and 40ft in the high cube version (HC) are needed, showed hereunder for convenience with related overall dimensions ad weights.

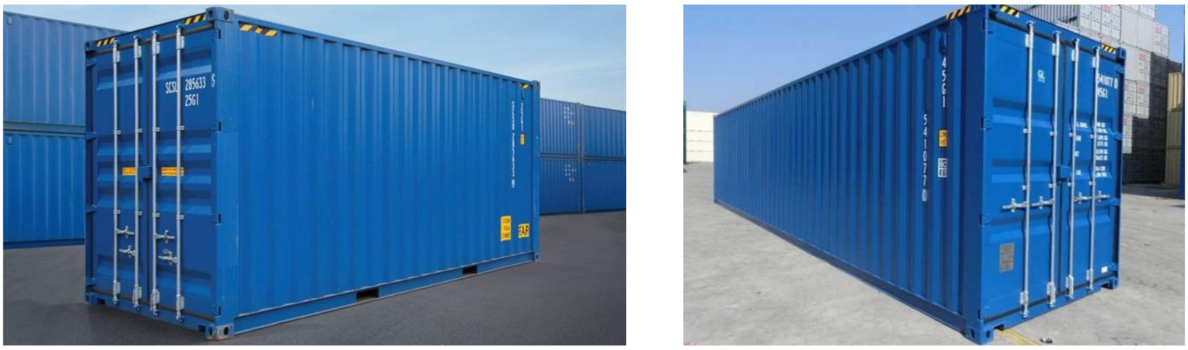


Figure 134: 20ft and 40ft HC ISO Container

High Cube Containers					
External	20′	40′	Internal	20′	40′
Length	6.06m	12.19m	Length	5.90m	12.04m
Width	2.44m	2.44m	Width	2.35m	2.35m
Height	2.90m	2.90m	Height	2.70m	2.70m
Tare Weight	2,410kg	3,840kg	Max. Payload	28,070kg	26,580kg
Capacity	37.40m³	76.40m³	Dimensions & weight may differ marginally depending on manufacturer.		

Figure 135: 20ft and 40ft HC ISO container overall dimensions and weights

The Feed Indexer overall dimensions are 0.1m x 2.5m x 2.3m (H) and the overall weight is about 1400kg. The next picture show both sides of a Feed Indexer placed in the vertical position.

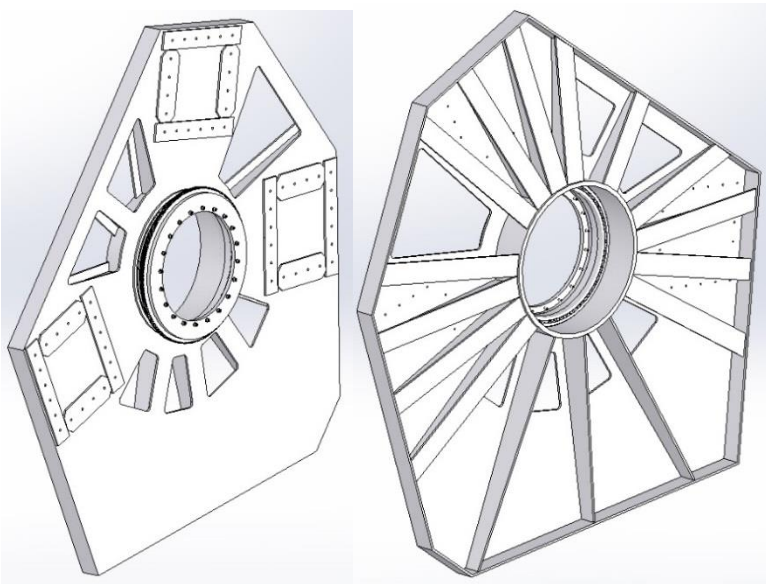


Figure 136: Feed Indexer

The feed indexer will be packaged onto a wooden custom pallet, compliant to ISPM15 FAO standard, that will be secured to the container inner tie-down rings by suitable retaining PES belts. The pallet has 10 vertical bricks in the front and rear side to avoid any feed indexer relative movement.

To place the feed indexer onto the pallet an overhead travelling crane or a 3T fork-lift truck with some retaining PES belts are needed. Up to 4 Feed Indexer can be packaged onto each pallet.

The hereunder pallet has an overall weight of about 1,000kg.

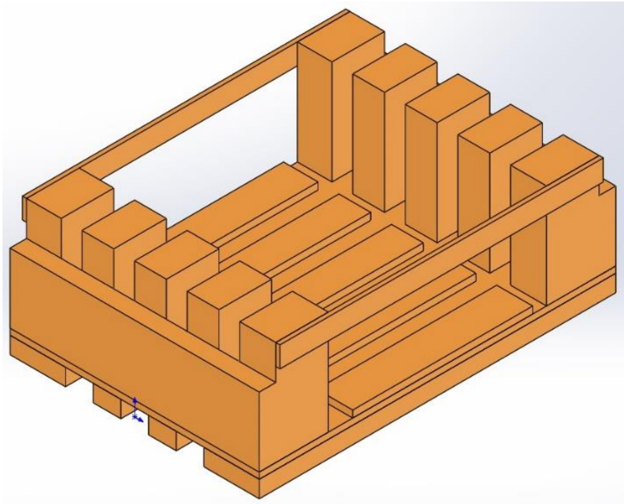


Figure 137: Feed Indexer custom pallet

To transport the Feed Indexer prototype to China a 20ft High Cube ISO container is needed. Up to 4 Feed Indexer can be transported (see next pictures) with a delivery time of about 30 days.

The Feed Indexer is secured to pallet with suitable retaining PES belts provided with metallic hook and locking device. The pallet is secured likewise to container inner tie-down rings.

Figure 138: Feed Indexer Prototype Transport in 20ft ISO HC Container

To transport the feed indexer series to South Africa a 40ft High Cube ISO container is needed.
Up to 16 feed indexers can be transported with a delivery time of about 45 days.
The feed indexers are secured with wooden pallets and suitable retaining PES belts provided with metallic hooks and locking devices. Likewise, the pallets are secured to inner container tie-down rings.

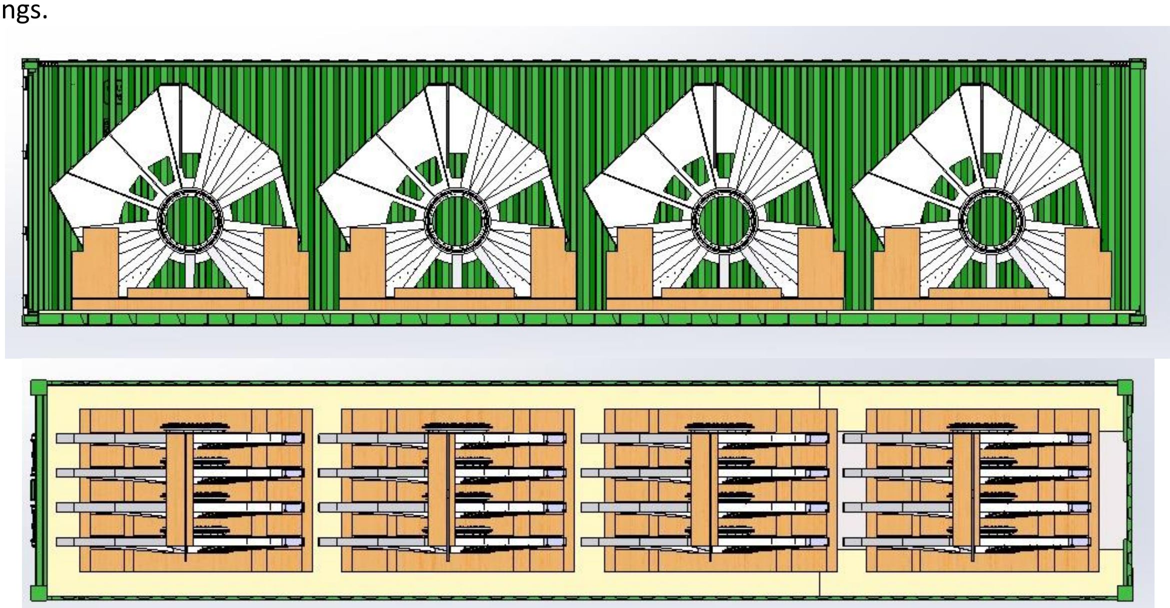


Figure 139: 16 Feed Indexer series transport in 40ft ISO HC Container

Each pallet with 4 Feed Indexer is placed into the 40ft container by a 10T fork-lift truck.

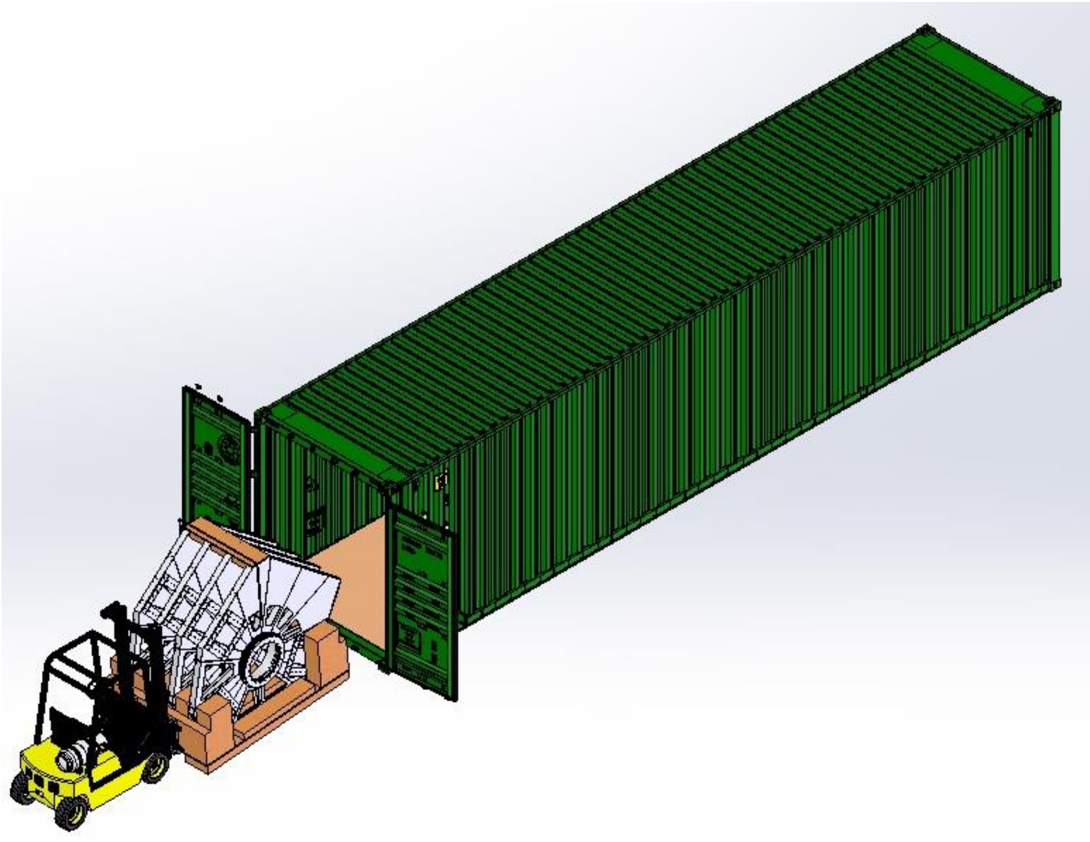


Figure 140: Handling of Feed Indexer into container by a 10T fork-lift truck

3.2.5.15 Finite Element Analysis

The Feed Indexer Finite Element Model has been built by using both shell ad solid elements.

The number of active FE elements in the model are the following:

- 87.487 linear shell elements
- 244.452 hexahedral linear solid elements
- 622.759 quadratic tetrahedral solid elements

The number of active nodes in the model is equal to 1.470.735.

The feeds have been simulated with a rigid beam connected to the support interface surface by means of "Distributed Couplings" connections. The feed mass is positioned on the feed gravity center (on one side of the beam), while the feed focus is on the other side of the beam. The electronic boxes (positioned on the platform), the motors and the Encoder box (positioned below the platform) have been simulated with a mass element in the gravity center and connected to the platform in the same way of the Feed rigid beams.

The "Distributed Couplings" connections allow the transmission of the inertial forces without the introduction of fictious stiffnesses in the model.

The FE model is shown in the following figures.

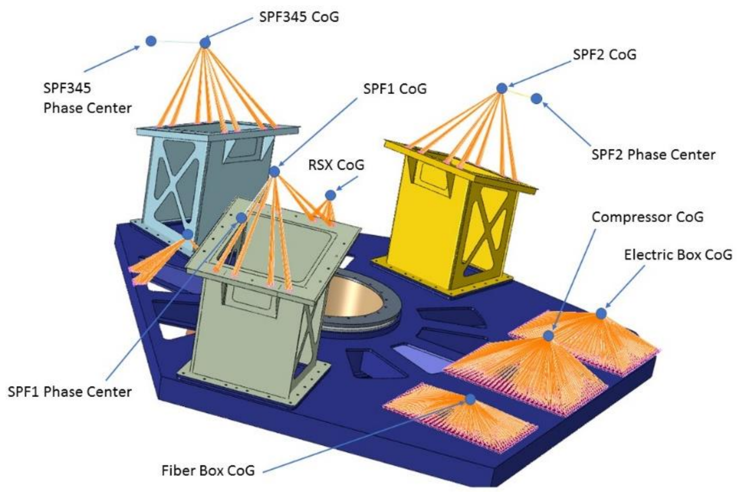


Figure 141: FE Model - Added mass

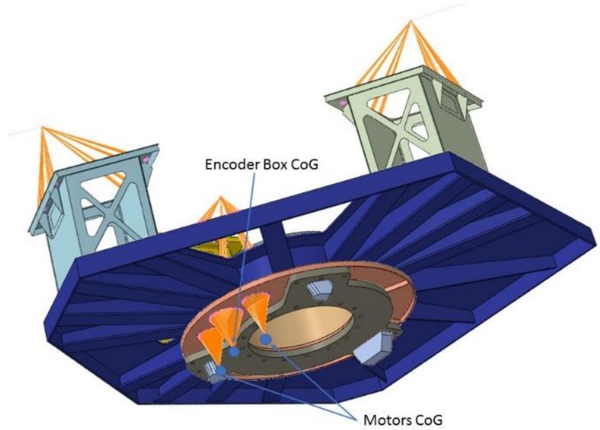


Figure 142: FE Model - Added mass

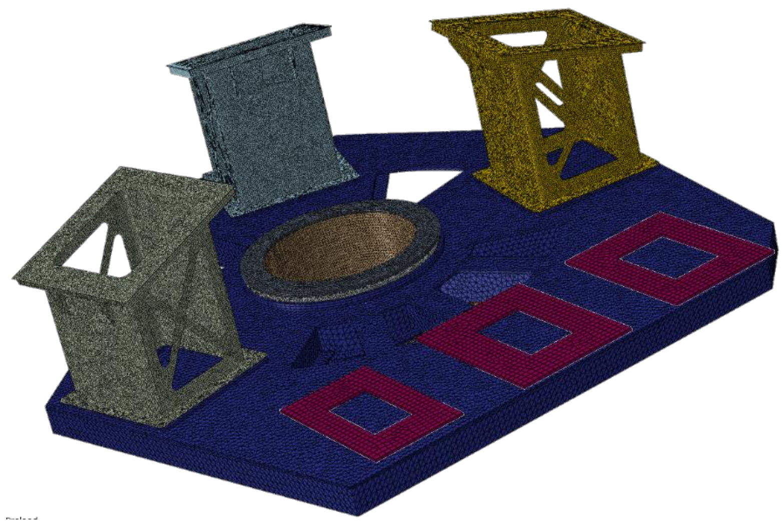


Figure 143: FE Model – Deformable Components

Compared to the previous simulations, the simulation of the tapered roller bearings has been inserted in FE model. The following aspects have been considered (see next figure):

- Preloaded Springs
- Contact surface of the upper bearing (no friction)
- Contact surface of the lower bearing (no friction)
- Sliding surface between the upper bearing and the internal cylinder to allow the preload simulation (no friction)

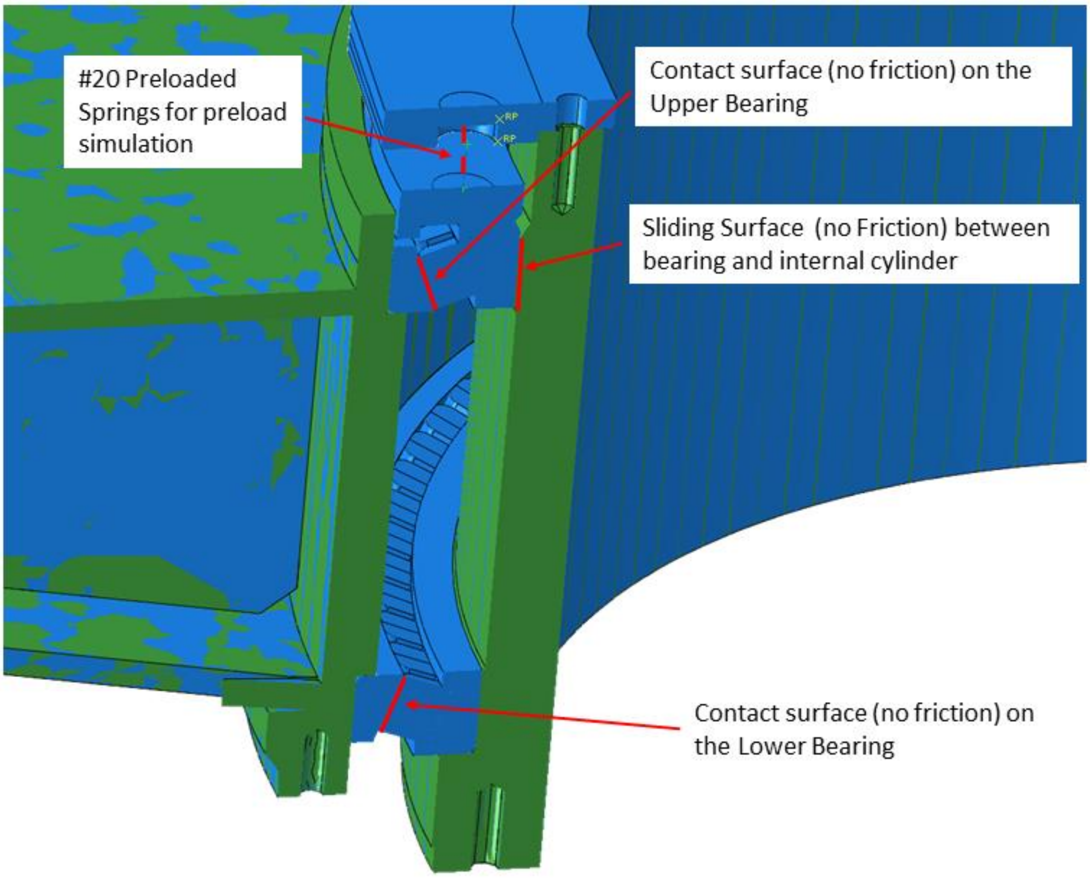


Figure 144: FE Model – Tapered roller bearings FE model

Also, the simulation of the driveline flexibility has been introduced in the FE model on the basis of the FE analyses reported in the par. 3.1.1.6.

The model has been constrained to the ground on the six attaching points of the hexapod system connecting the Feed Indexer with the Telescope Structure. Each of the six points has been constrained along a single DOF parallel to the hexapod pole connected with the point itself.

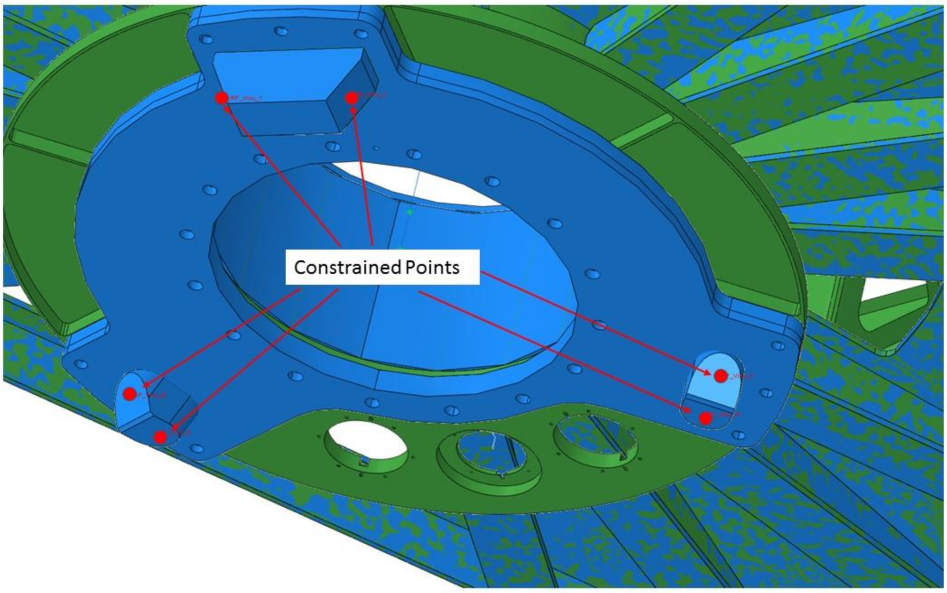


Figure 145: FE Model – Constrained Points

The inertial loads (Dead Weight) have been applied to the structure by means of a gravity field acting on each element and mass of the FE model.

In order to simulate the Feed Indexer deformation due to Dead Weight, nine load conditions have considered in the FE analyses:

- Feed indexer in Feed Band 1 position with three telescope elevations (15°, 52.5°, 90°)
- Feed indexer in Feed Band 2 position with three telescope elevations (15°, 52.5°, 90°)
- Feed indexer in Feed Band 5 position with three telescope elevations (15°, 52.5°, 90°)

The FE results have been used to evaluate the compliance of the Feed Indexer Design with the Stability requirement R.FI.003 and R.FI.004 (see the following table).

FEED INDEXER CONFIGURATION - Feed Indexer Final Design - Roller Bearing simulation - Driveline flexibility simulation		**DEAD WEIGHT - FEEDs PHASE CENTER DISPLACEMENTS AND ROTATIONS**			**R.FI.03** **Feed Indexer Deflection Position**		**R.FI.04** **Feed Indexer Deflection Orientation**	
FEED INDEXER POSITION		Telescope Elevation : 15° Platform Elevation : 0°	Telescope Elevation : 52.5° Platform Elevation : 37.5° (Reference Angle)	Telescope Elevation : 90° Platform Elevation : 75°	Target value (mm)	Actual value (mm)	Target value (Deg)	Actual value (Deg)
FEED Band 1 aligned	Phase Center axial displacement (X axis) (mm)	-0,136	0,226	0,499	0,50	0,439	0,50	0,018
	Phase Center Transverse displacement (Y axis) (mm)	-0,038	-0,061	-0,069				
	Phase Center Vertical displacement (Z axis) (mm)	-0,181	0,067	0,272				
	Phase Center rotation around X axis (Deg)	0,001	0,001	0,000				
	Phase Center rotation around Y axis (Deg)	-0,007	0,012	0,026				
	Phase Center rotation around Z axis (Deg)	0,000	0,002	0,003				
FEED Band 2 aligned	Phase Center axial displacement (X axis) (mm)	-0,153	0,163	0,397	0,50	0,385	0,50	0,015
	Phase Center Transverse displacement (Y axis) (mm)	0,007	0,020	0,023				
	Phase Center Vertical displacement (Z axis) (mm)	-0,192	0,028	0,206				
	Phase Center rotation around X axis (Deg)	-0,001	0,000	0,000				
	Phase Center rotation around Y axis (Deg)	-0,007	0,008	0,020				
	Phase Center rotation around Z axis (Deg)	0,000	-0,001	-0,002				
FEED Band 345 aligned	Phase Center axial displacement (X axis) (mm)	-0,153	0,220	0,499	0,50	0,455	0,50	0,019
	Phase Center Transverse displacement (Y axis) (mm)	0,041	0,086	0,105				
	Phase Center Vertical displacement (Z axis) (mm)	-0,193	0,062	0,271				
	Phase Center rotation around X axis (Deg)	-0,002	-0,004	-0,004				
	Phase Center rotation around Y axis (Deg)	-0,007	0,011	0,026				
	Phase Center rotation around Z axis (Deg)	0,000	0,000	-0,001				

Figure 146: FE Results – Displacements and Rotations for the 9 used load conditions

The displacements values reported in the previous table are referred to the coordinate system shown in the figure below.

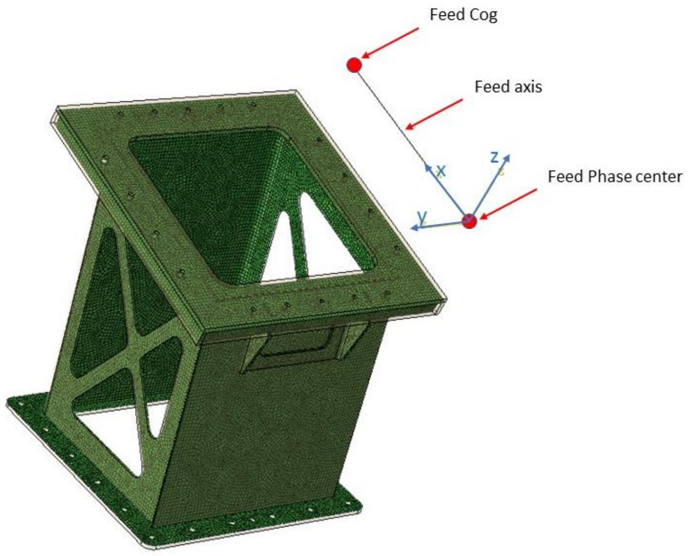


Figure 147: FE Results – Displacements coordinate system used in the table in Fig. 53

The calculated displacements are compliant with the requirements R.FI.03 and R.FI.04 (FI stability requirements).

The worst load conditions for the three Feed Indexer positions are related to the Telescope elevation of 90°. The more critical Feed is the Band 345 Feed.

In the following figures the displacement and stress distributions, in the worst case, are reported.

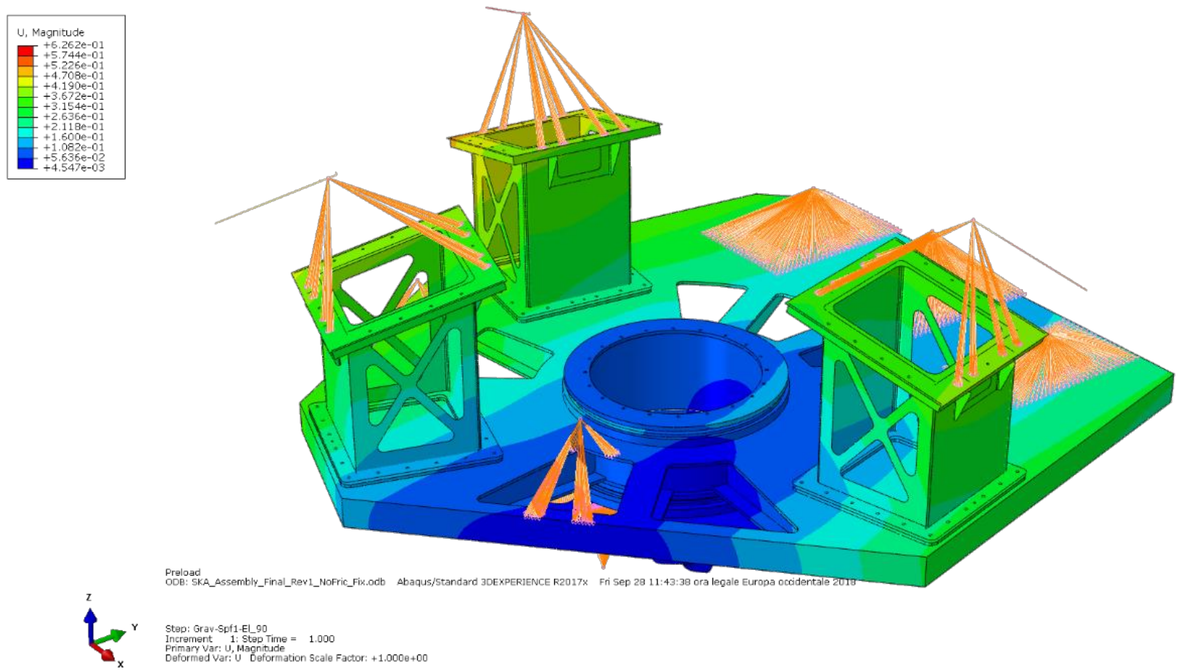


Figure 148: FE Results – Total displacements field (Band 1 Feed – 90° Elevation)

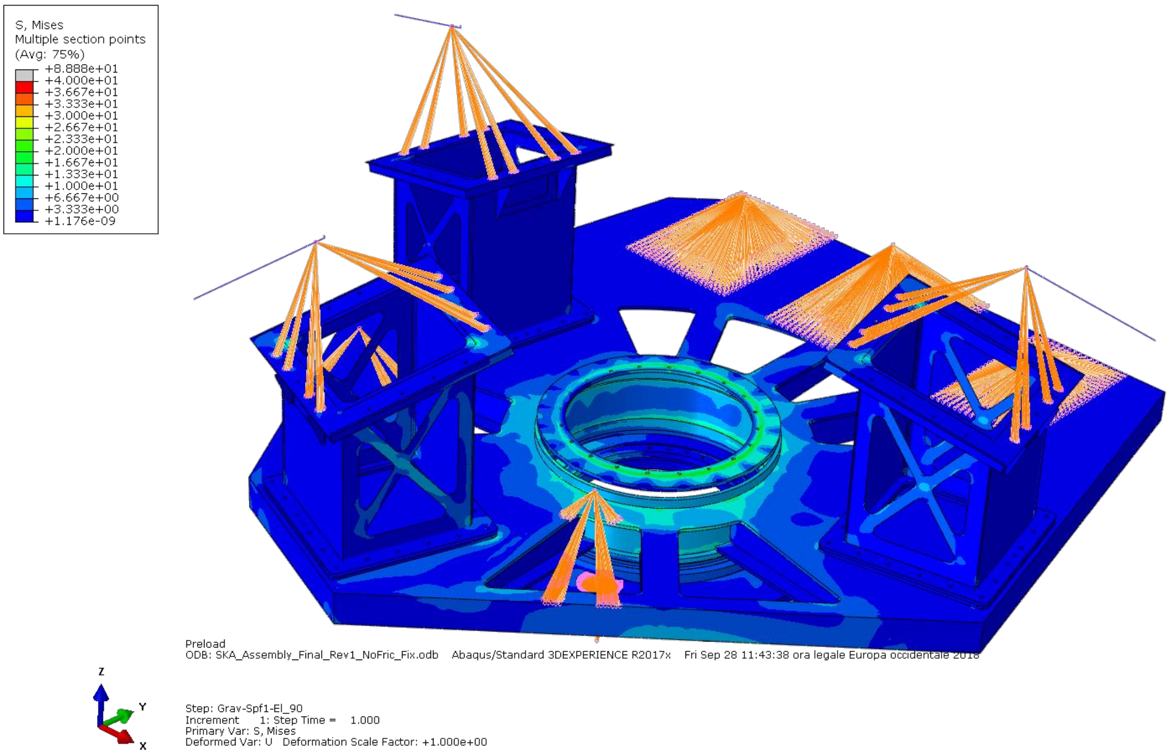


Figure 149: FE Results – Von Mises stress field (Band 1 Feed – 90° Elevation)

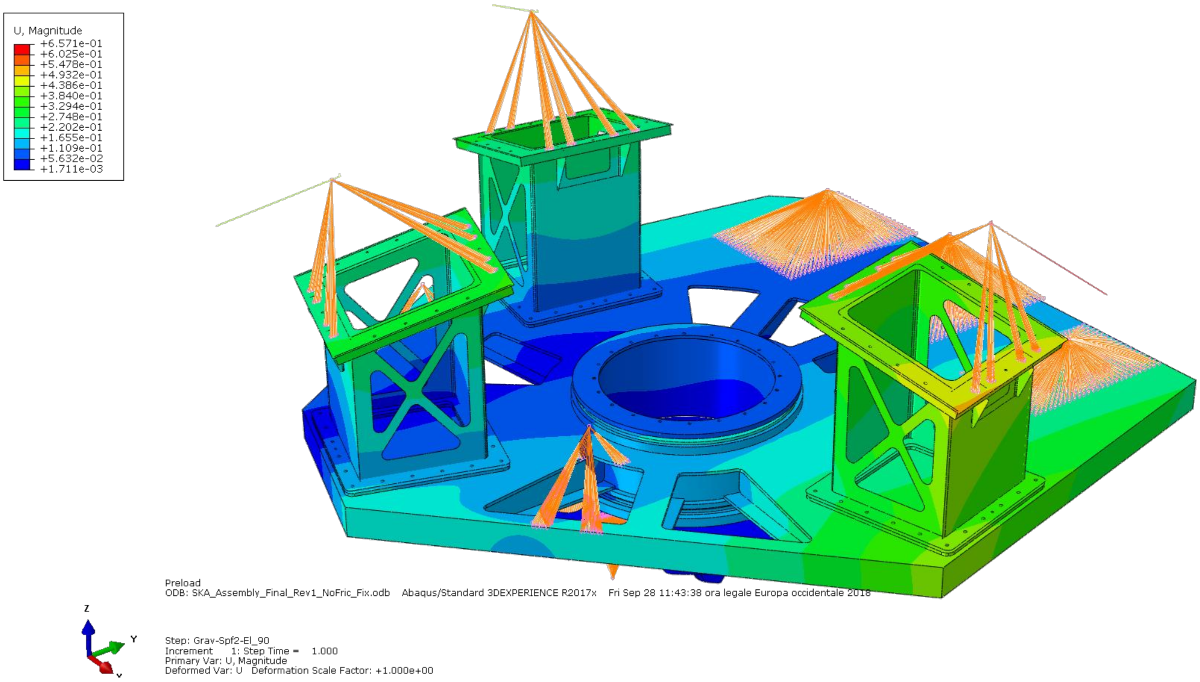


Figure 150: FE Results – Total displacements field (Band 2 Feed – 90° Elevation)

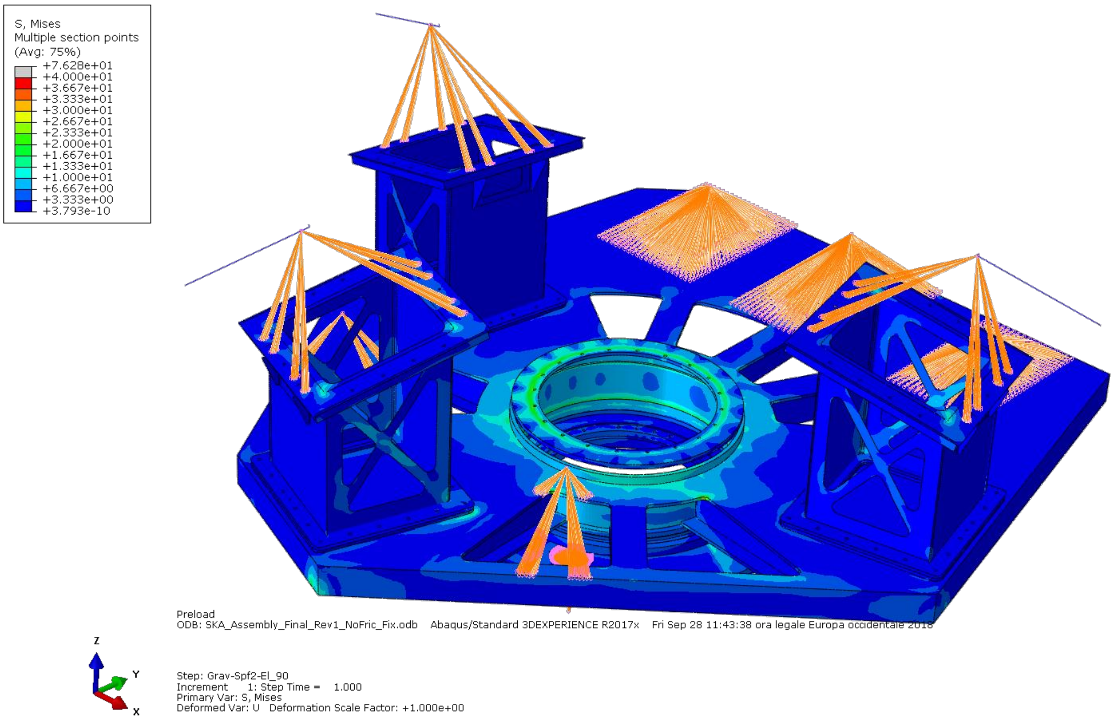


Figure 151: FE Results – Von Mises stress field (Band 2 Feed – 90° Elevation)

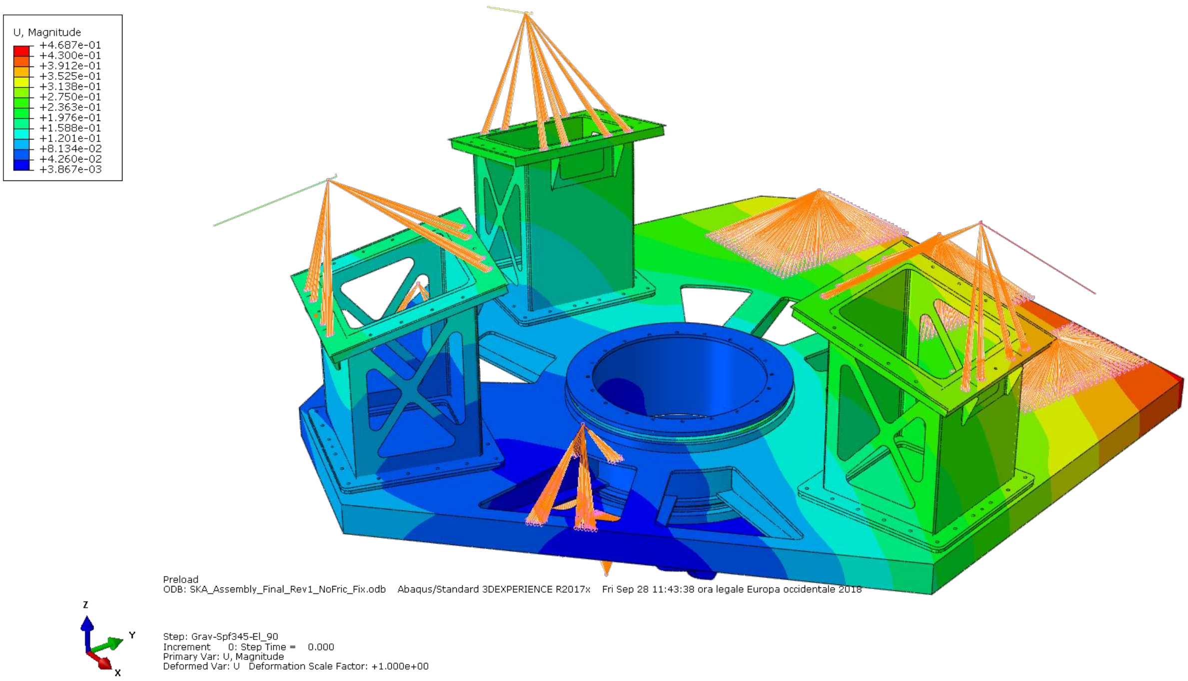


Figure 152: FE Results – Total displacements field (Band 345 Feed – 90° Elevation)

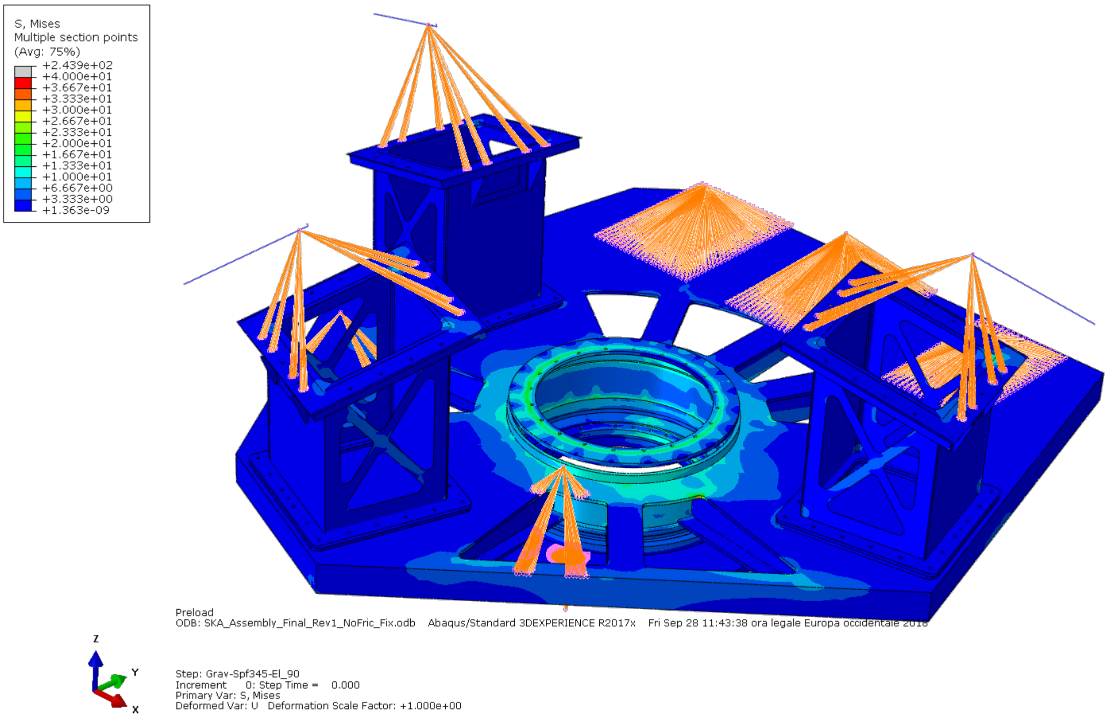


Figure 153: FE Results – Von Mises stress field (Band 345 Feed – 90° Elevation)

Main results of the analysis from the stress level point of view are listed below:

- No structural issues observed: stress levels are abundantly below the allowable limits (max 40 MPa). Only in very few small zones the stress level reach 90 MPa;
- The Feeds focus maximum displacements and rotations are compliant with the stability requirements;

3.2.5.16 Cable Routing

The design of the cable routing has been carried out in order to define the route of each cable and pipe located on the rotating platform. The design has been carried out in such a way to protect cables and pipes against bumping/pulling and allow the maintenance of devices mounted on the platform.
A walkable cover is provided too, it has to protect the cables during the maintenance of the feeds and the equipment on the FI. The cover is characterized by four different removable pieces, but it is possible to work on the cables also with the cover mounted in fact there is enough space between the platform and the cover (see the figure below).

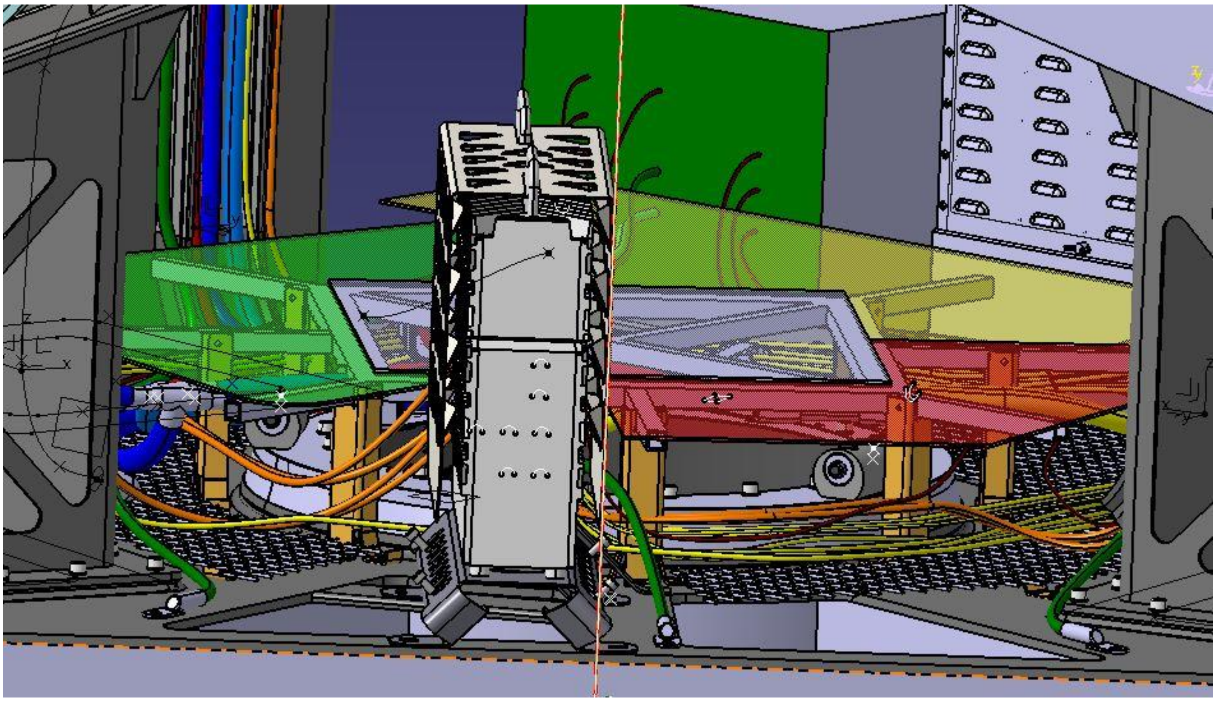
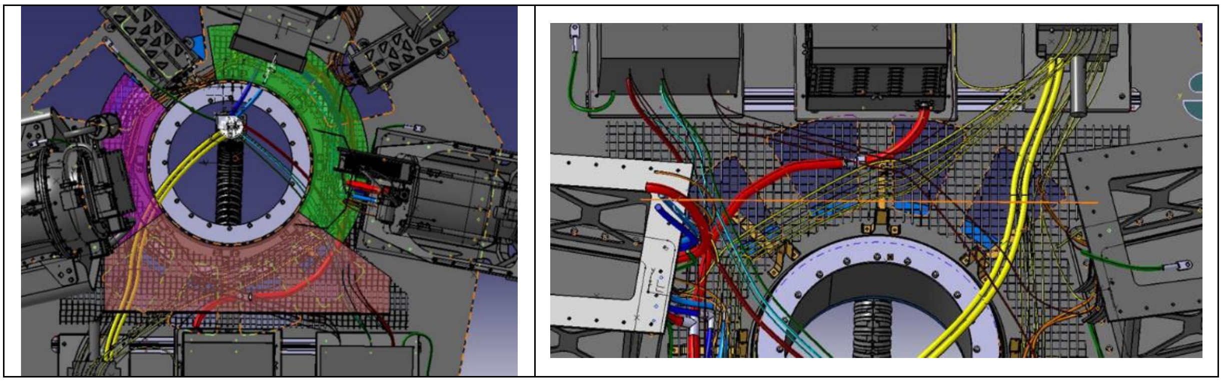
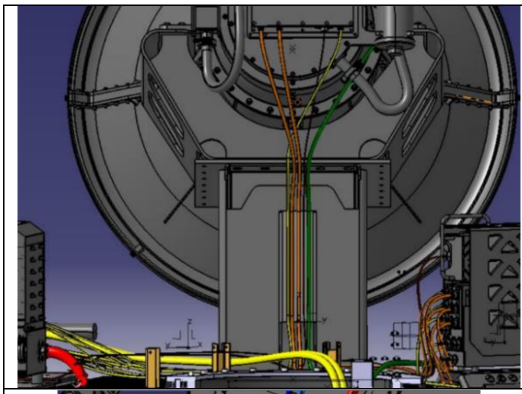
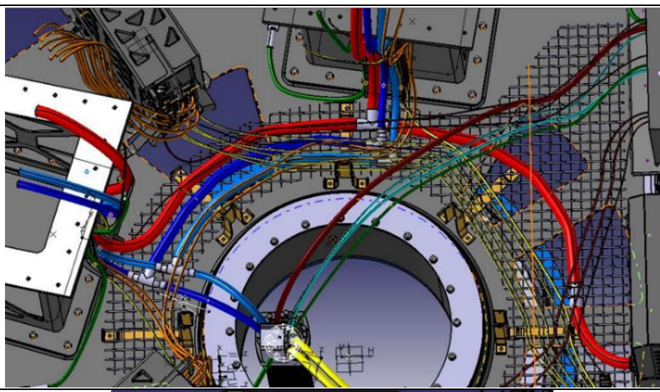
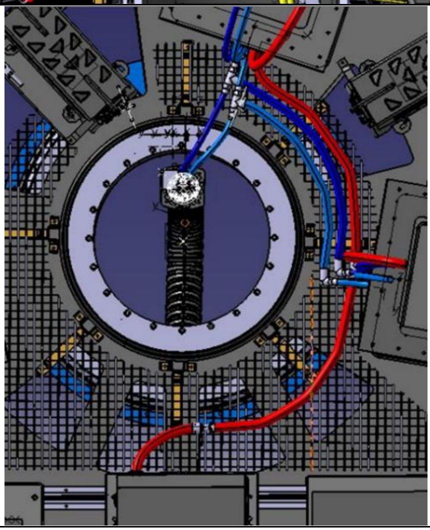
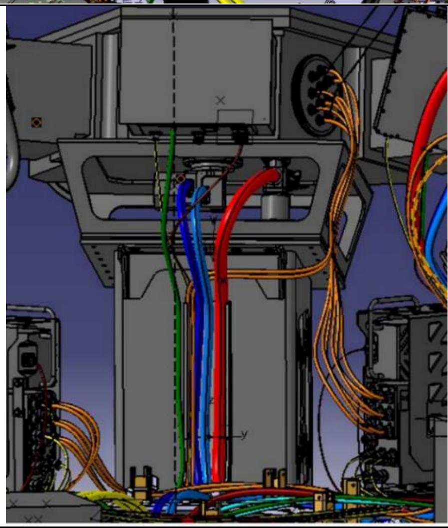
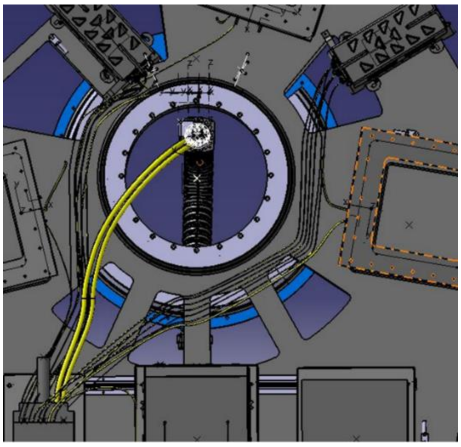
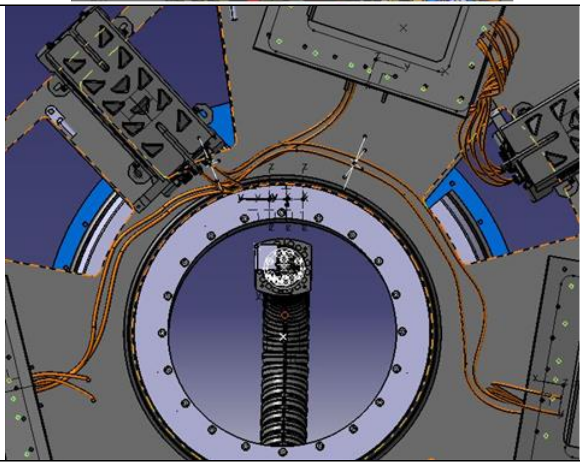


Figure 154: Cable Routing 1

The design was organized in two phases:

1. Firstly, a meticulous design was carried out, the cables and tubes were designed using the CAD CATIA V5 design software, in this way it was possible to define ideal paths and lengths for each individual cable. Below are some screenshots of the CATIA V5 software:



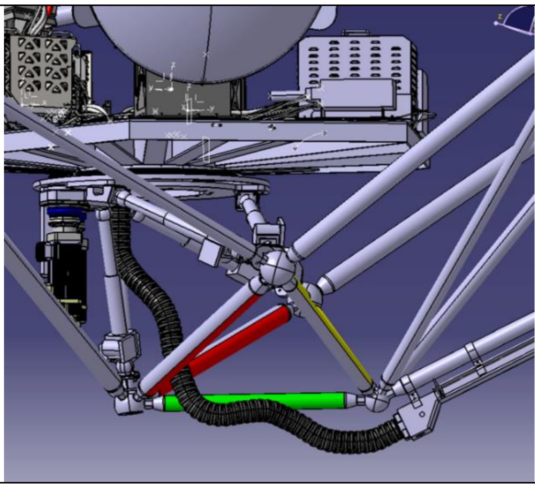


Figure 155: Cable Routing 2

2. The second phase was characterized by the real simulation of cables and pipes by means of dummies that were installed on the Feed Indexer at the Fantini Sud workshop.
   Conditions very close to reality have been created, even pressurized pipes (20 Bar) passing inside the Triflex Igus duct, of which it was necessary to test the flexibility, have been simulated.

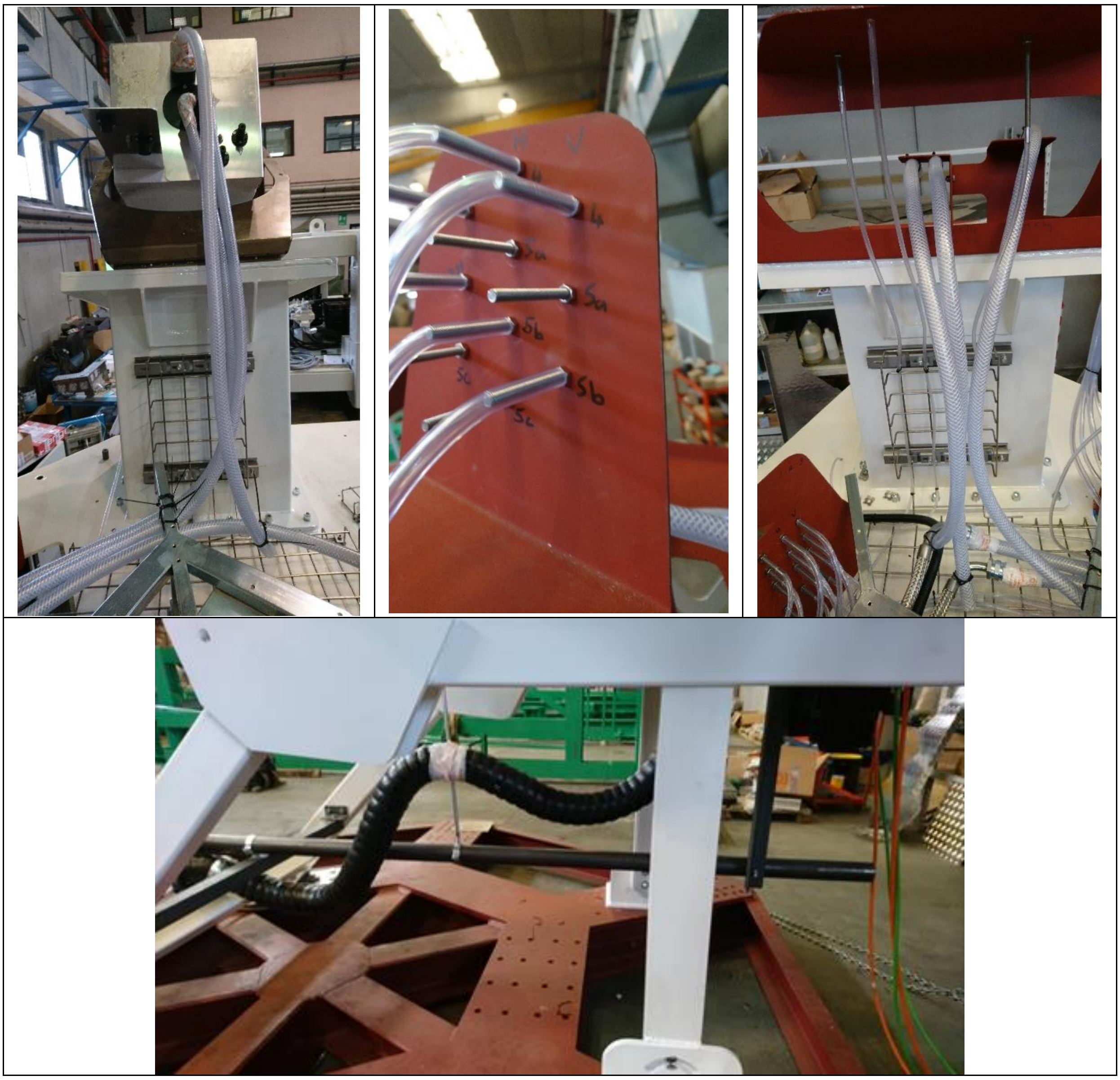


Figure 156: Cable Routing 3

In the following table all the cables and pipes installed on the platform and their characteristics are listed:

Table 23 Cable routing (Cables/Pipes list)

Part of	Item of interest	From	To	Length [mm]	Diameter	MIN Bending radius (static)	MIN Bending radius (dynamic)
SPFVa	Vacuum Manifold Hose	Vacuum Pump Enclosure ~~Compressor~~	Vacuum Manifold	260	29mm	70mm	180mm
SPFVa	Vacuum Manifold	n/a	n/a	720	25.4mm (29mm)	50mm	n/a
SPFVa	Vacuum Feed Hose	Vacuum Manifold	SPF Band 2	1200	29mm	70mm	180mm
SPFVa	Vacuum Feed Hose	Vacuum Manifold	SPF Band 345	1700	29mm	70mm	180mm
SPFHe	Generic Helium Feed Hose	SPF Band 2	Helium Supply Manifold	1010	19mm	60mm	150mm
SPFHe	Generic Helium Feed Hose	SPF Band 2	Helium Return Manifold	1010	19mm	60mm	150mm
SPFHe	Generic Helium Feed Hose	SPF Band 345	Helium Supply Manifold	1050	19mm	60mm	150mm
SPFHe	Generic Helium Feed Hose	SPF Band 345	Helium Return Manifold	1050	19mm	60mm	150mm
SPFHe	Helium Supply Manifold	Generic Helium Feed Hose	Generic Indexer Hose	650	25.4mm	50mm	n/a
SPFHe	Helium Return Manifold	Generic Helium Feed Hose	Generic Indexer Hose	650	25.4mm	50mm	n/a
SPFHe	Generic Indexer Hose	Helium Supply Manifold	Generic Helium Support Arm Hose	350	19mm	60mm	150mm
SPFHe	Generic Indexer Hose	Helium Return Manifold	Generic Helium Support Arm Hose	405	19mm	60mm	150mm
SPFRx	RF COAX SPF 1 - V	SPF 1 Package	SPFRx Sampler 123	2250	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 1 - H	SPF 1 Package	SPFRx Sampler 123	2260	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 2 - V	SPF 2 Package	SPFRx Sampler 123	2280	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 2 - H	SPF 2 Package	SPFRx Sampler 123	2300	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 3 - V	SPF 345 Package	SPFRx Sampler 123	1890	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 3 - H	SPF 345 Package	SPFRx Sampler 123	1880	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 4 - V	SPF 345 Package	SPFRx Sampler 45	1050	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 4 - H	SPF 345 Package	SPFRx Sampler 45	1060	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 5a - V	SPF 345 Package	SPFRx Sampler 45	850-900	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 5a - H	SPF 345 Package	SPFRx Sampler 45	850-900	8mm (TBC)	100mm (TBC)	n/a
SPFRx	RF COAX SPF 5b - V	SPF 345 Package	SPFRx Sampler 45	1060	8mm (TBC)	100mm (TBC)	n/a

SPFRx	RF COAX SPF 5b - H	SPF 345 Package	SPFRx Sampler 45	1060	8mm (TBC)	100mm (TBC)	n/a
DFN	SPF1 Fibre Cable	SPF 1 Package	DFN Indexer Fibre Routing Panel	2010	5.8mm	60mm	n/a
DFN	SPF2 Fibre Cable	SPF 2 Package	DFN Indexer Fibre Routing Panel	2810	5.8mm	60mm	n/a
DFN	SPF345 Fibre Cable	SPF 345 Package	DFN Indexer Fibre Routing Panel	2830	5.8mm	60mm	n/a
DFN	SPF Va Fibre Cable	SPF Vacuum Pump	DFN Indexer Fibre Routing Panel	1700	5.8mm	60mm	n/a
DFN	RXS123 Fibre Cable, Data & CAM A	SPFRx Sampler 123	DFN Indexer Fibre Routing Panel	1770	5mm	50mm	n/a
DFN	RXS123 Fibre Cable, Data & CAM B	SPFRx Sampler 123	DFN Indexer Fibre Routing Panel	1575-1600	5mm	50mm	n/a
DFN	RXS123 Fibre Cable, Data & CAM C	SPFRx Sampler 123	DFN Indexer Fibre Routing Panel	1575-1600	5mm	50mm	n/a
DFN	RXS45 Fibre Cable, Data & CAM A	SPFRx Sampler 45	DFN Indexer Fibre Routing Panel	2520	5mm	50mm	n/a
DFN	RXS45 Fibre Cable, Data & CAM B	SPFRx Sampler 45	DFN Indexer Fibre Routing Panel	1930-1950	5mm	50mm	n/a
DFN	RXS45 Fibre Cable, Data & CAM C	SPFRx Sampler 45	DFN Indexer Fibre Routing Panel	1950-2000	5mm	50mm	n/a
DFN	RXS45 Fibre Cable, Data & CAM D	SPFRx Sampler 45	DFN Indexer Fibre Routing Panel	1896-2000	5mm	50mm	n/a
DFN	RXS45 Fibre Cable, Data & CAM E	SPFRx Sampler 45	DFN Indexer Fibre Routing Panel	1896-2000	5mm	50mm	n/a
DFN	Riser Cable, MultiMode (inside conduit)	DFN Indexer Fibre Routing Panel	DFN Shielded Cabinet Fibre Routing Panel	1300	5.8mm(20mm)	60mm(200mm)	150mm(200mm)
DFN	Riser Cable, SingleMode (inside conduit)	DFN Indexer Fibre Routing Panel	DFN Shielded Cabinet Fibre Routing Panel	1300	5.8mm(20mm)	60mm(200mm)	150mm(200mm)
DFN	RXS123 Fibre Cable, CLK&PPS	SPFRx Sampler 123	DFN Indexer Fibre Routing Panel	1655-1700	3mm	30mm	n/a
DFN	RXS123 Fibre Cable, CLK Loop	SPFRx Sampler 123	DFN Indexer Fibre Routing Panel	1615-1700	3mm	30mm	n/a
DFN	RXS45 Fibre Cable, CLK&PPS	SPFRx Sampler 45	DFN Indexer Fibre Routing Panel	1952-2000	3mm	30mm	n/a
DFN	RXS123 Fibre Cable, Noise Diode	SPFRx Sampler 123	DFN Indexer Fibre Routing Panel	1575-1600	5.8mm	60mm	n/a
DS Power Distribution	Power Cable,SPF 1	SPF 1 Package	Indexer PDU	2590	4mm	TBD(CETC54)	TBD(CETC54)

DS Power Distribution	Power Cable,SPF 2	SPF 2 Package	Indexer PDU	1850	4mm	TBD(CETC54)	TBD(CETC54)
DS Power Distribution	Power Cable,SPF 345	SPF 345 Package	Indexer PDU	2460	4mm	TBD(CETC54)	TBD(CETC54)
DS Power Distribution	Power Cable, SPF Va	SPF Vacuum Pump	Indexer PDU	2440	4mm	TBD(CETC54)	TBD(CETC54)
DS Power Distribution	Power Cable,SPFRx Sampler 123	SPFRx Sampler 123	Indexer PDU	2820	4mm	TBD(CETC54)	TBD(CETC54)
DS Power Distribution	Power Cable,SPFRx Sampler 45	SPFRx Sampler 45	Indexer PDU	1810	4mm	TBD(CETC54)	TBD(CETC54)
DS Power Distribution	Power Cable, Indexer	Indexer PDU	Pedestal PDU	1350	15mm	113mm	150mm
DS Power Distribution	Protective Earth, Indexer	Indexer PDU	Pedestal PDU	1250	8mm	65mm	80mm
DS Control System	FI DB CB Monitor	FI IO Unit	Feed Indexer Power Distribution Box	1300	5.9mm	TBD(MTM)	TBD(MTM)
DS Control System	FI Emergency Stop	FI IO Unit	FI Emergency Stop Switch	1300	9mm (TBC)	TBD(MTM)	TBD(MTM)
DS Lightning Protection System	Earth Strap, SPF 1	SPF 1 Package	Indexer	1530	TBD	TBD(CETC54)	TBD(CETC54)
DS Lightning Protection System	Earth Strap, SPF 2	SPF 2 Package	Indexer	1290	TBD	TBD(CETC54)	TBD(CETC54)
DS Lightning Protection System	Earth Strap, SPF 345	SPF 345 Package	Indexer	1380	TBD	TBD(CETC54)	TBD(CETC54)
DS Lightning Protection System	Earth Strap, SPF Va	SPF Vacuum Pump	Indexer	360	TBD	TBD(CETC54)	TBD(CETC54)
DS Lightning Protection System	Earth Strap, SPFRx Sampler 123	SPFRx Sampler 123	Indexer		TBD	TBD(CETC54)	TBD(CETC54)
DS Lightning Protection System	Earth Strap, SPFRx Sampler 45	SPFRx Sampler 45	Indexer		TBD	TBD(CETC54)	TBD(CETC54)
DS Lightning Protection System	Earth Strap, Indexer PDU	Indexer PDU	Indexer	350	TBD	TBD(CETC54)	TBD(CETC54)

DS Lightning Protection System	EarthStrap, Indexer	Indexer platform (steel structure)	Elevation Assembly (Steel Structure)	700	TBD	TBD(CETC54)	TBD(CETC54)

3.2.5.16.1 Cable-Wrap Concept

A cable wrap concept has been designed too. Specifically, an “Igus” duct is used in order to lead cables and pipes from the top of the platform down the cabinet passing through the Feed Indexer hole.

Cables and pipes which go down to the pedestal passing through the FI hole are listed in the following table:

Table 24 Cable Wrap (Cables/Pipes list)

N	Part of	Count	From	To	Diameter	MIN Bending radius (dynamic)	Length, CW included [mm]
	CABLE WRAP						
1	**SPFHe**	1	Helium Supply Manifold	Generic Helium Support Arm Hose	19mm	150mm	3000+350 mm (cable wrap)
2	**SPFHe**	1	Helium Return Manifold	Generic Helium Support Arm Hose	19mm	150mm	3000+405 mm (cable wrap)
C1 (3,4)	**DFN**	3(1)	DFN Indexer Fibre Routing Panel	DFN Shielded Cabinet Fibre Routing Panel	5.8mm(20mm)	150mm(200mm)	3000+1300 mm (cable wrap)
C2 (5,6)	**DFN**	1(1)	DFN Indexer Fibre Routing Panel	DFN Shielded Cabinet Fibre Routing Panel	5.8mm(20mm)	150mm(200mm)	3000+1300 mm (cable wrap)
10	**DS Power Distribution**	1	Indexer PDU	Pedestal PDU	15mm	150mm	3000+1350 mm (cable wrap)
11	**DS Power Distribution**	1	Indexer PDU	Pedestal PDU	8mm	80mm	3000+1250 mm (cable wrap)
12	**DS Control System**	1	FI IO Unit	Feed Indexer Power Distribution Box	5.9mm	TBD	3000+1300 mm (cable wrap)
13	**DS Control System**	1	FI IO Unit	FI Emergency Stop Switch	9mm (TBC)	TBD	3000+1300 mm (cable wrap)
14	**DS Lightning Protection System**	1	Indexer platform (steel structure)	Elevation Assembly (Steel Structure)	TBD	TBD	3000+700 mm (cable wrap)

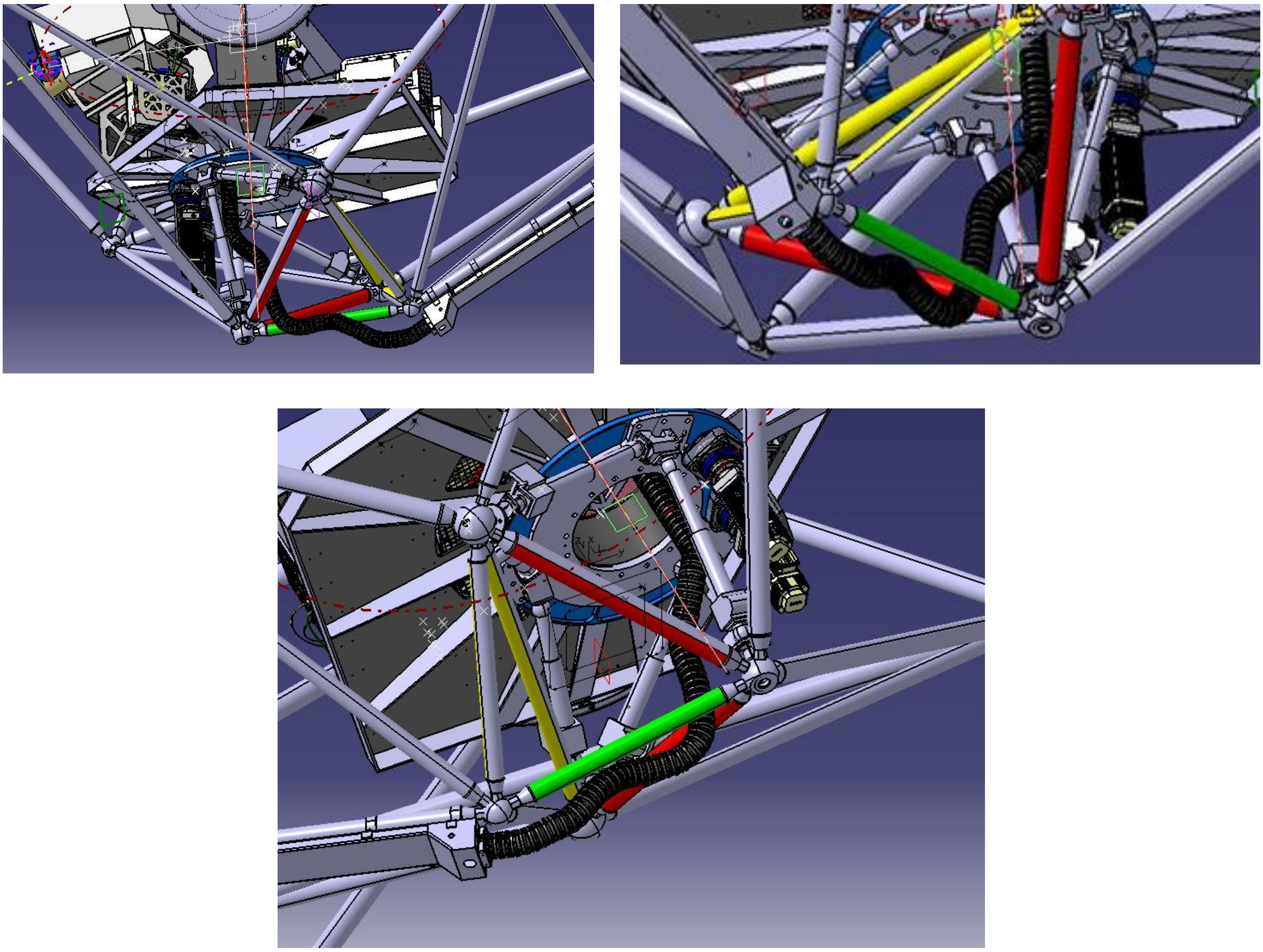


Figure 157: Cable Wrap

In order to do it has been decided to use an IGUS duct (3000-3500 mm long), specifically a System triflex® R series TRE.100, whose characteristics are:

- **Multi-axis movement - High flexibility for complex applications even on the 6th axis. Rotation of approx. ± 10° per chain link possible along the longitudinal axis. This facilitates cable routing around difficult geometric shapes**
- **High tensile force absorption due to the "ball and socket" joint, meaning smooth movements in all axes**
- **Easy opening mechanism - for easy filling and replacement of pre-assembled cables or hoses**
- **Outstanding mechanical characteristics**
- **Small bend radii and pitch for space-saving installation**
- **Easy to lengthen and shorten - one injection-moulded part. No supporting elements (e.g. steel cables, spring mechanisms etc.) necessary along the direction of tensile force**
- **Extremely stable - due to stops on the outside, precise stops for radius and torsion**
- **triflex® R set - Compact universal module for all movements at the robot, is mounted on existing fastening points**
- **Set-up times minimised due to very easy connection to the structure and comprehensive accessories**

The position of each cable/pipe inside the duct is very important, so it was studied in a specific way (see the table 20 and the following figure, and consider that at this stage the PAF cables are not considered). The goal was to reduce as much as possible the twist of the cables and especially of the helium hoses. In order to do it the fixing point of the duct has been positioned very close to the edge of the FI hole (far away from the centre of the hole) in order to force the hoses to bend around the bottom fixing point and not to twist.
In the figure below is possible to see the position of each cable/pipe inside the IGUS duct and the dimensions of them (the numbers indicate the ID of the cables/pipes, see the table).

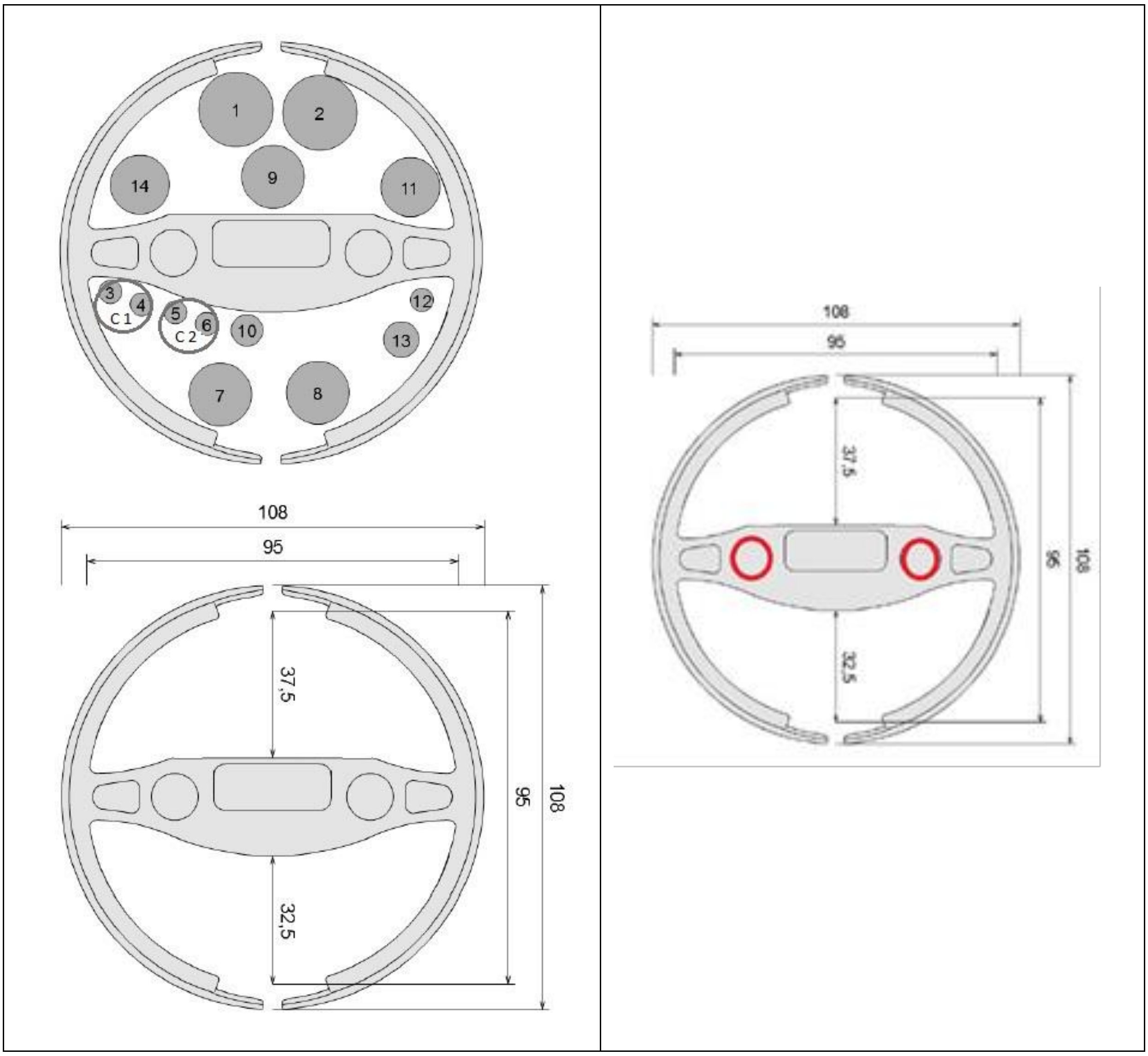
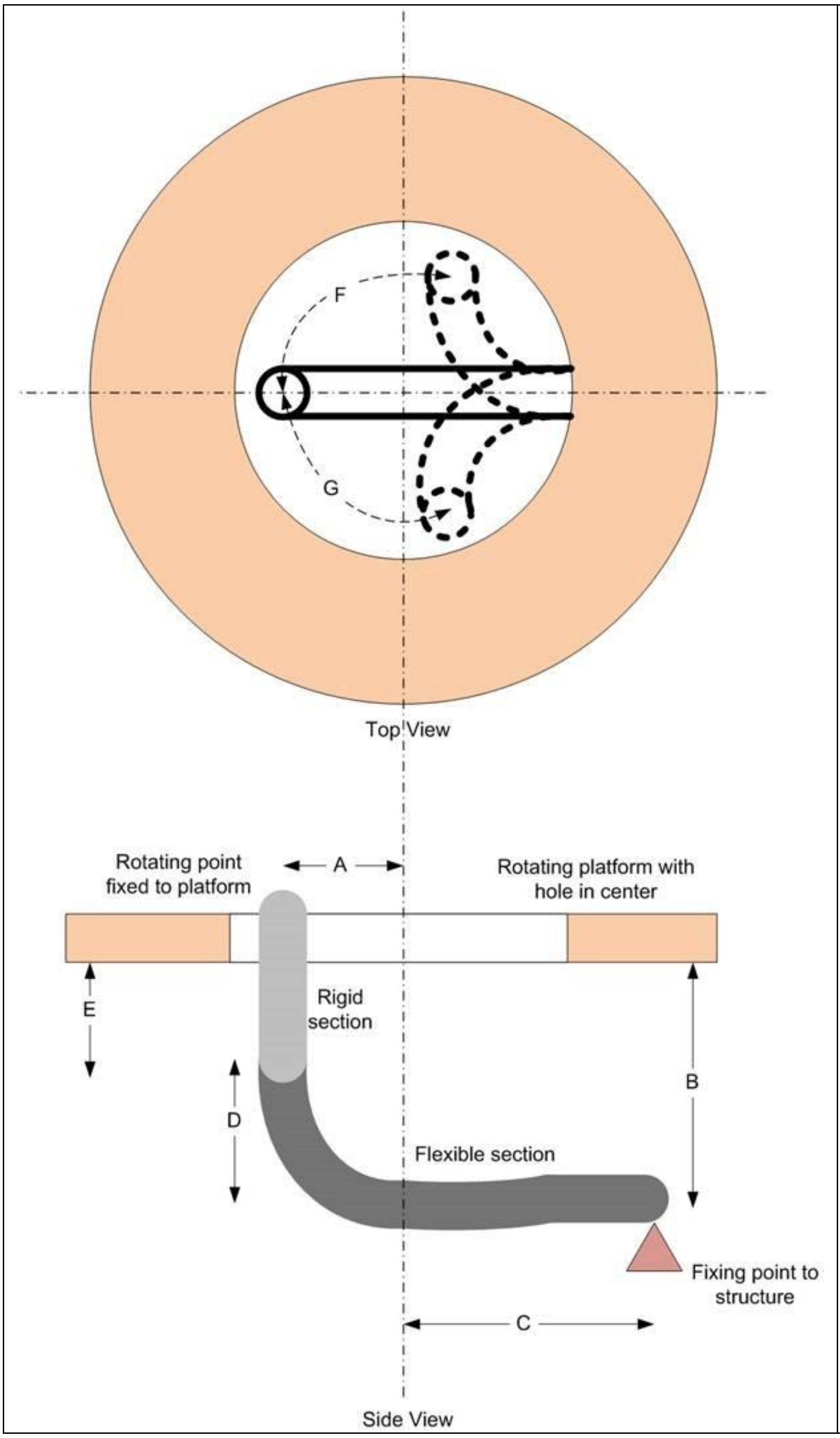


Figure 158 Igus Duct and cables/pipes positions, glass fibre rods positions

In order to reduce the twist of the first part of the IGUS duct (from the upper fixing point to the section in which it starts to turn, around 600 mm) and consequently the cables/pipes' twist, two glass fibre sticks are inserted inside the two holes indicated in the figure above.

Regarding the fixing connection points between the cable wrap and the structure, following figure provides the dimensions (A to G) defined during the factory integration, in order to optimize the behaviour of the cable wrap during the rotation at the different elevations.



A = 156 mm
B = 620 mm
C = 450 mm
D = 340 mm
E = 280 mm

F = 103,4° / 281 mm
G = 100° / 270 mm

Figure 159 Igus Duct fixing connection points

3.2.5.17 Design differences between SKA-P and SKA-MPI

Some design improvements have been applied to SKA-MPI prototype respect to SKA-P prototype. Following list summarized the main differences:

1. **EMI Feed Indexer** control Box **upgrade:**
    - to add filters, glands and waveguides
    - gasket and mounting concept design improvement
    - Encoder shaft EMI protection

The SKA-P version control box is shown in following figure.

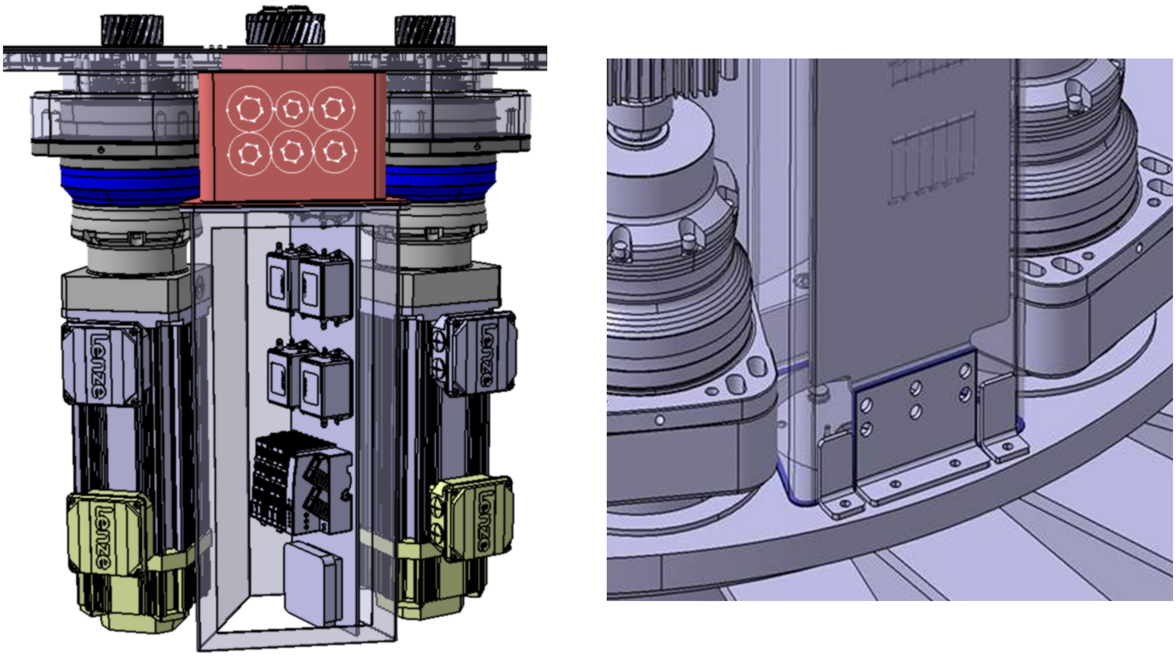


Figure 160 SKA-P control box

2. **Grease selection, in order to have the same lubrication for all the antenna mechanisms (see paragraph 3.2.5.7).**

3. **Test support equipment improvement, in order to speed factory test and allow «cable wrap functional test» (see paragraph 3.2.5.13).**

4. **Cable routing and cable-wrap fixing accessories and guiding devices modifications. An example (cable wrap bracket) is shown below.**

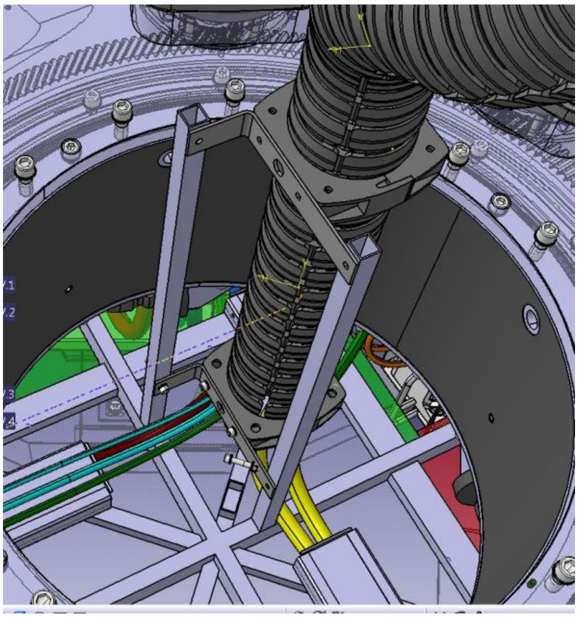


Figure 161 SKA-MPI Cable Wrap bracket detail.

5. Safety connection point for fall provision, close to the centre of the indexer and not protruding above stepping surface. See following figure.

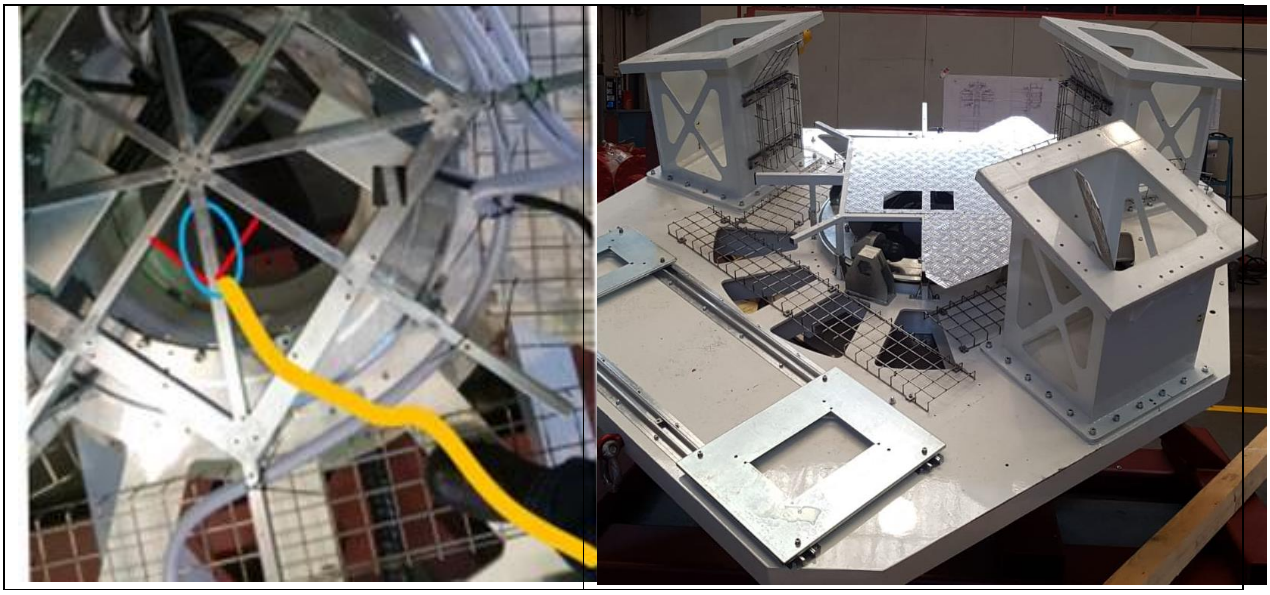


Figure 162 SKA-MPI safety connection access point

6. Bearing and gears covers design improvement.

The SKA-P version and SKA-MPI version covers are shown in following figures.

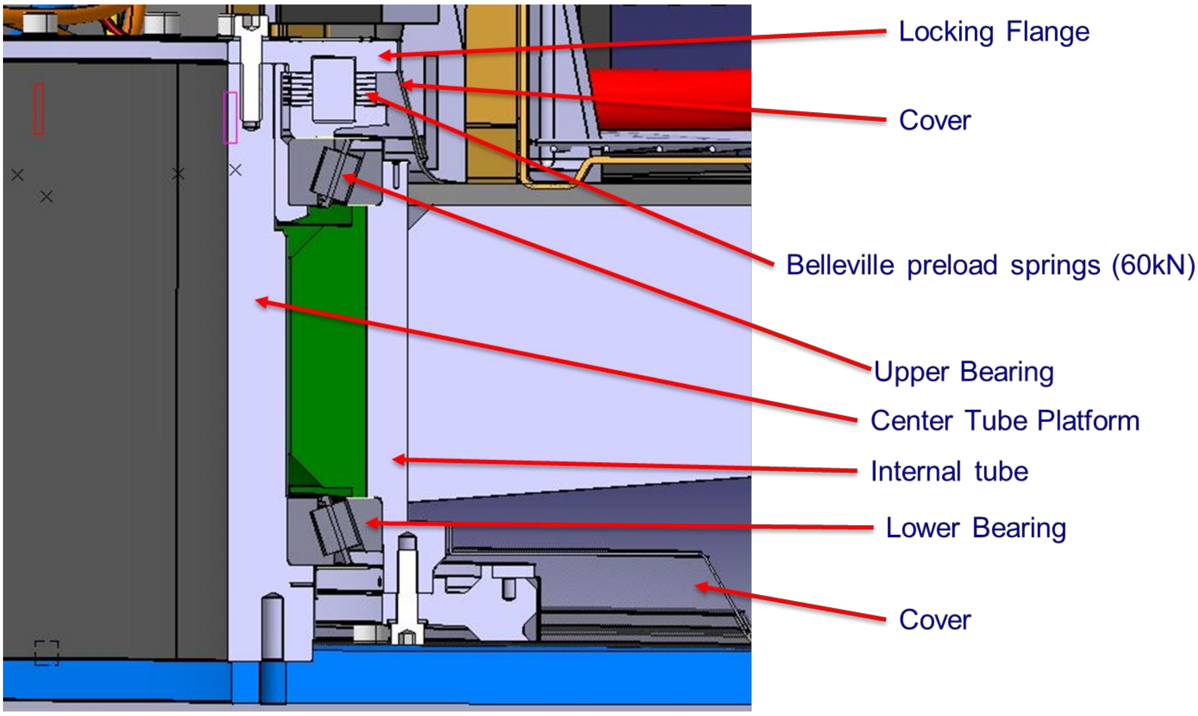


Figure 163 SKA-P covers.

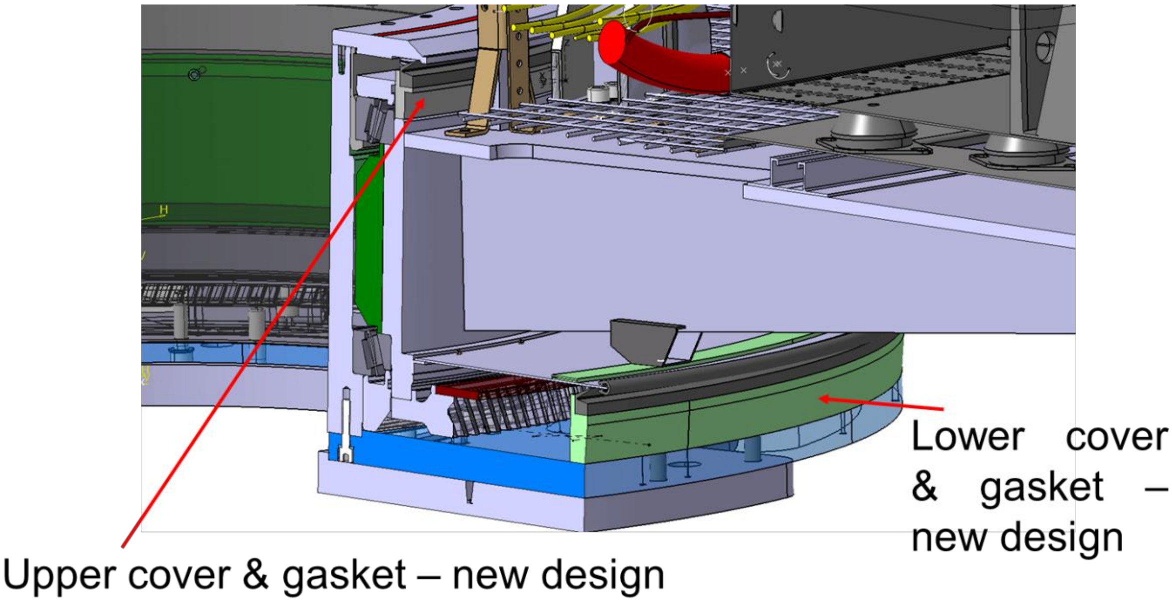


Figure 164 SKA-MPI covers.

3.2.6 Power Distribution

The context of dish power distribution is shown in Figure 165.

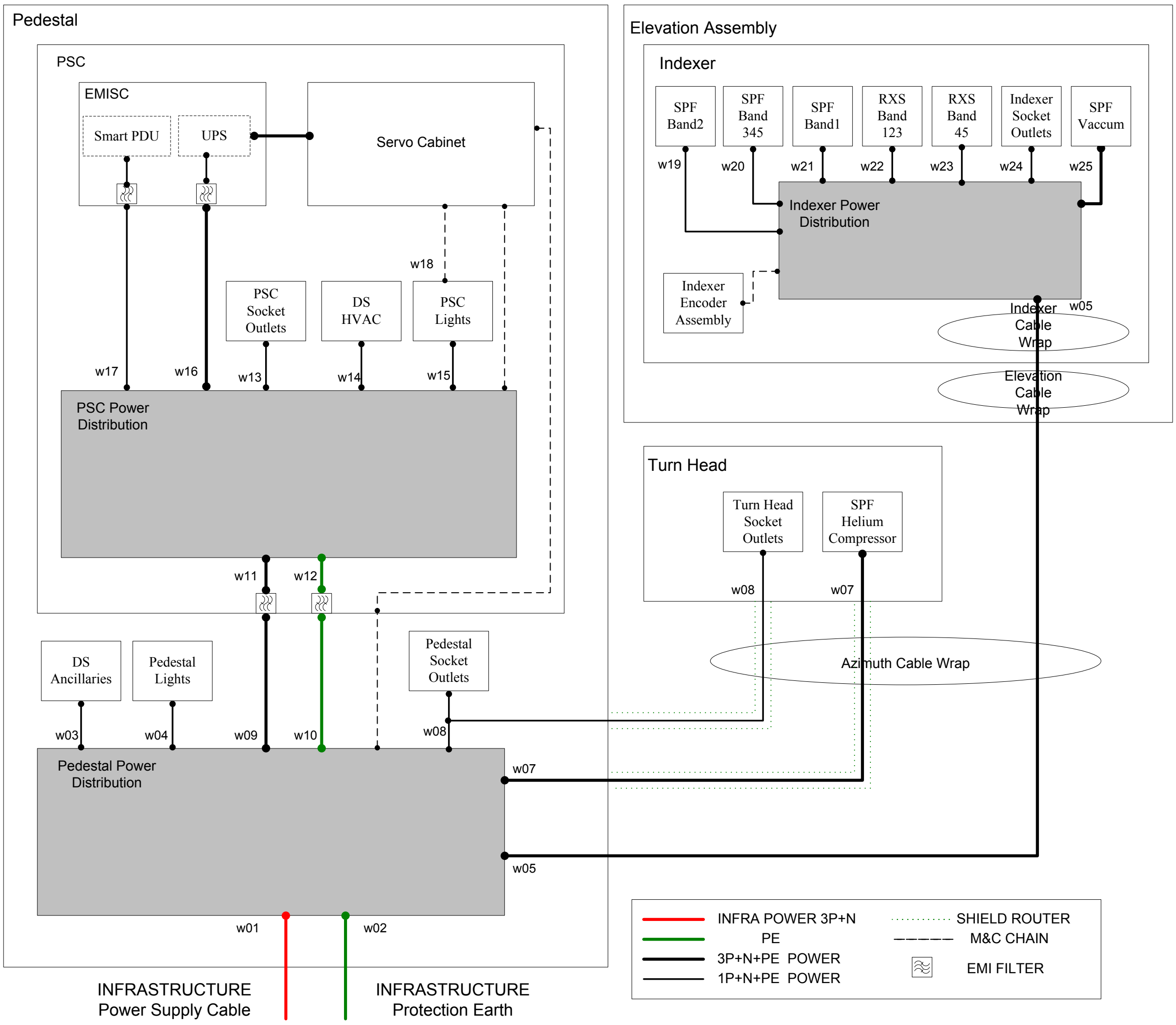


Figure 165: The Context of Power Distribution

The Power Distribution main sub-elements include:

- Pedestal power distribution
- PSC power distribution
- Indexer power distribution

The design of Power Distribution is based on the definitions of [AD1] SKA-TEL-DISH-0000041 SKA1 DISH ELEMENTS POWER MANAGEMENT,REV01. It distributes the supply power from Infrastructure to all work-elements in pedestal. If supply power is outage, it can provide backup power by using an UPS to stow the dish and maintain the communication with Telescope Manager. Note that the UPS is not currently included in the design. The shield router represents the metallic cable conduits for the cable outside the dish.

The Design is also under the guidance of [AD2] 301-000000-018 DEVELOPER GUIDELINES TO SANA 10142-1 & SAN60950-1 FOR DSH ELECTRICAL SAFETY. Power distribution also provides electrical safety protection for power surge, leakage and over-currents etc.

3.2.6.1.1 Pedestal Power Distribution

The pedestal power distribution is located in the lower section pedestal, above the foundation power cable entry, as shown in Figure 166. The box is mounted behind the ladder with certain distance. The cover is bolted onto the box, which can be moved for maintenance.

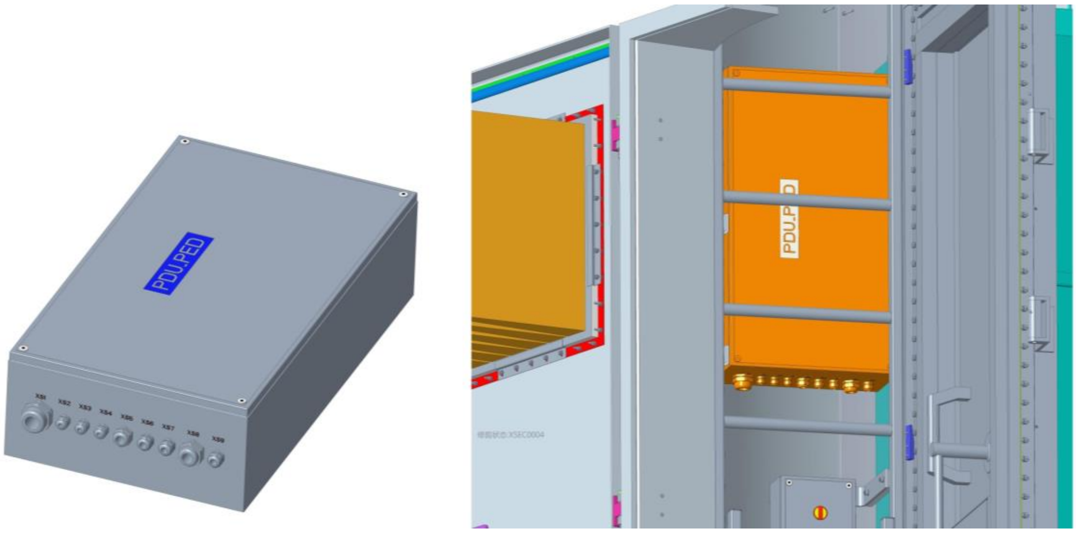


Figure 166: 3D Model and Position of Pedestal Power Distribution

The diagram of pedestal power distribution is shown in Figure 167.

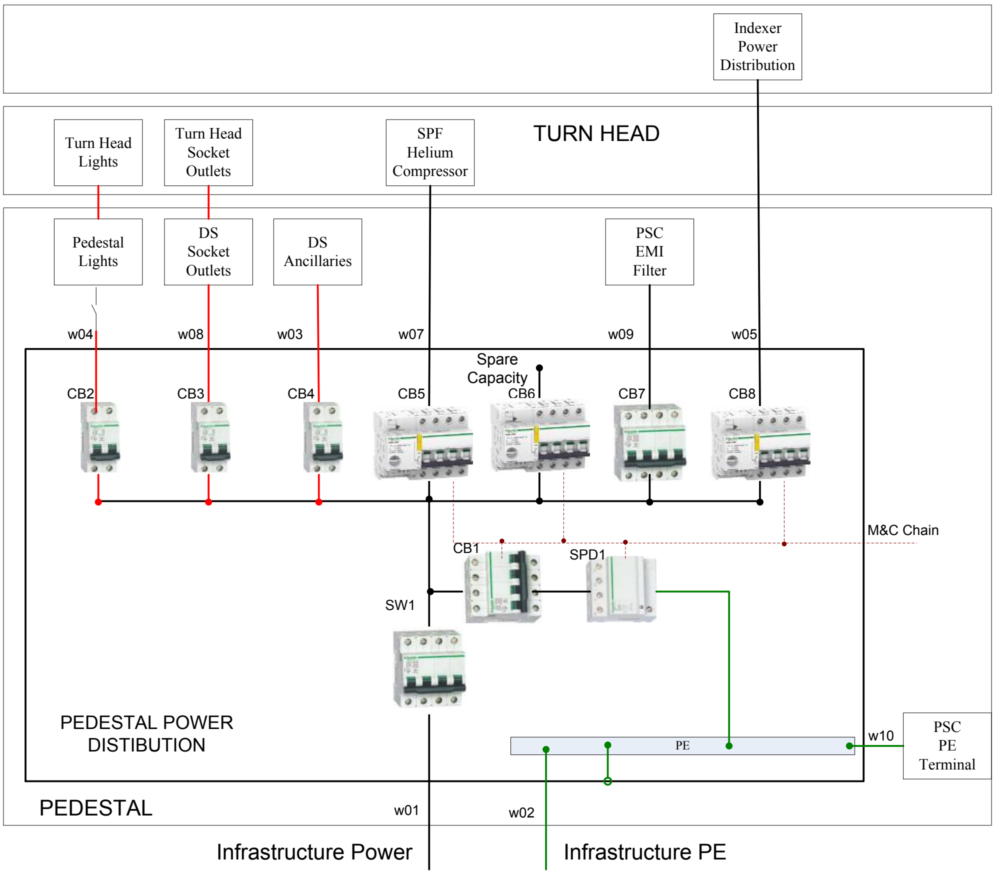


Figure 167: Diagram of Pedestal Power Distribution

The main parts of Pedestal Power Distribution are shown in Table 25.

Table 25: Main Parts of Pedestal Power Distribution

Part No.	Type	Voltage	Current	Protection	Monitor	Remote
SW1	Schneider iINT125 4P 100A	~400VAC	100A	over-current isolation	n	n
CB1	Schneider iC65N-C63A/4P iOF	~400VAC	63A	over-current	1 NO point	+24VDC
CB2	Schneider iC65N-C16A/2P	~230VAC	16A	over-current	n	n
CB3	Schneider iC65N-C20A/2P Vigi iC65 ELE	~230VAC	20A	over-current Leakage:30 mA	n	n
CB4	Schneider iC65N-C16A/2P	~230VAC	16A	over-current	n	n
CB5	Schneider iC65N-D32A/4P RCA	~400VAC	32A	over-current	1 NO point	+24VDC
CB6	Schneider iC65N-D32A/4P RCA	~400VAC	32A	over-current	1 NO point	+24VDC
CB7	Schneider iC65N-D63A/4P	~400VAC	63A	over-current	n	n
CB8	Schneider iC65N-D20A/4P RCA	~400VAC	20A	over-current	1 NO point	+24VDC
SPD1	Schneider iPRF1 12.5r 3P+N	L-N 350V N-PE，260V	Iimp：12.5kA In：25kA	Up：≤1.5kV	n	n

3.2.6.1.2 PSC Power Distribution

The PSC power distribution is located inside the PSC, below the EMISC as shown in Figure 168. The distribution box is applied with lockable wheels and bolted cover for maintenance work.

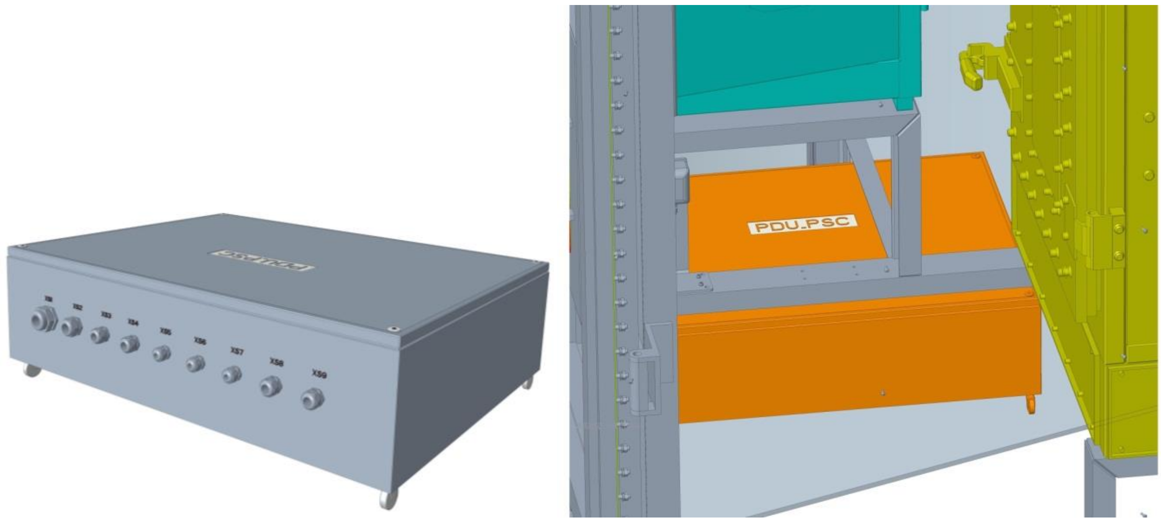


Figure 168: 3D Model and Position of PSC Power Distribution

The diagram of PSC power distribution is shown in Figure 169.

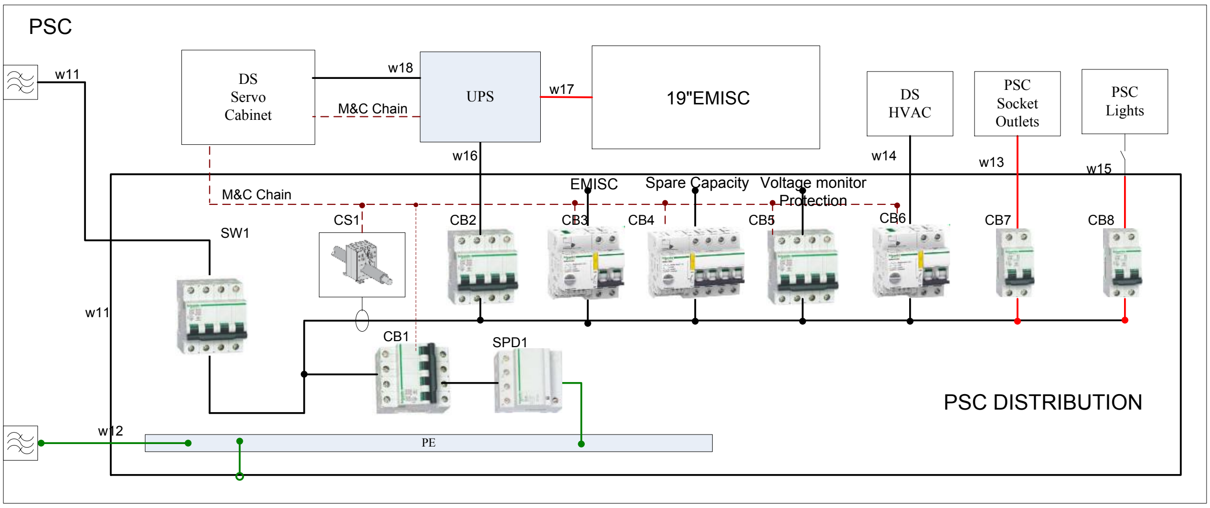


Figure 169: Diagram of PSC Power Distribution

The main parts of PSC Power Distribution are shown in Table 26.

Table 26: Main Parts of PSC Distribution

Part No.	Type	Voltage	Current	Protection	Monitor	Remote
SW1	Schneider iINT125 4P 80A	~400VAC	80A	over-current isolation	n	n
CB1	Schneider iC65N-C40A/4P iOF	~400VAC	40A	over-current	1 NO point	n
CB2	Schneider iC65N-D40A/4P	~400VAC	40A	over-current	n	n
CB3	Schneider iC65N-D20A/2P RCA	~230VAC	20A	over-current	1 NO point	+24VDC
CB4	Schneider iC65N-D16A/4P RCA	~400VAC	16A	over-current	1 NO point	+24VDC
CB5	Schneider iC65N-B3A/4P	~400VAC	3A	over-current	n	n
CB6	Schneider iC65N-D6A/2P RCA	~230VAC	6A	over-current	1 NO point	+24VDC
CB7	Schneider iC65N-C20A/2P Vigi iC65 ELE	~230VAC	20A	over-current Leakage:30 mA	n	n
CB8	Schneider iC65N-C16A/2P	~230VAC	16A	over-current	n	n
SPD1	Schneider iPRU 40 3P+N	L-N 350V，N-PE，230V	In：20kA(8/20 μs) Imax：40kA(8/20μs)	Up：≤1.7kV（10kA，8/20μs）	n	n
CS1	Siemens 4NC5117-0CC20	Provided by MTM				

3.2.6.1.3 Indexer Power Distribution

The indexer power distribution is located on the rear of the feed indexer, beside the vacuum assembly, as shown in Figure 170. The distribution box is bolted on the bracket on the Indexer.

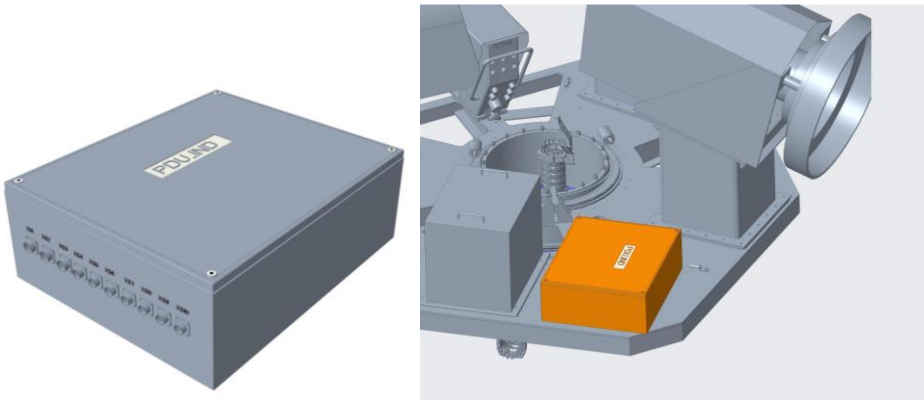


Figure 170: 3D Model and Position of Indexer Power Distribution

The diagram of Indexer Power Distribution is shown in Figure 171.

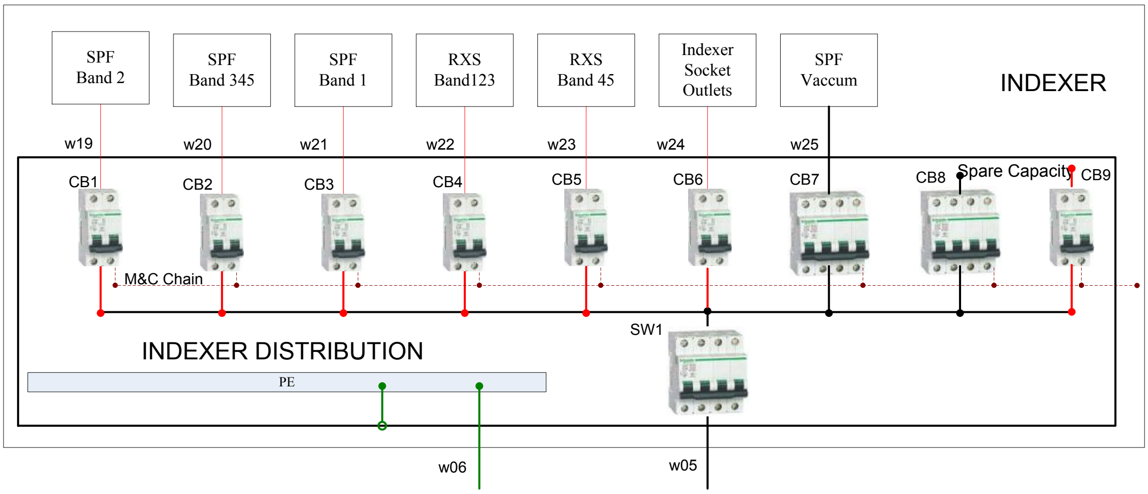


Figure 171: Diagram of Indexer Power Distribution

The main parts of Indexer Power Distribution are shown in Table 27.

Table 27: Main Parts of Indexer Power Distribution

Part No.	Type	Voltage	Current	Protection	Monitor	Remote
SW1	Schneider iINT125 4P 32A	~400VAC	32A	over-current isolation	n	n
CB1	Schneider iC65N-C6A/2P iOF	~230VAC	6A	over-current	1 NO point	n
CB2	Schneider iC65N-C6A/2P iOF	~230VAC	6A	over-current	1 NO point	n
CB3	Schneider iC65N-C6A/2P iOF	~230VAC	6A	over-current	1 NO point	n
CB4	Schneider iC65N-C6A/2P iOF	~230VAC	6A	over-current	1 NO point	n
CB5	Schneider iC65N-C6A/2P iOF	~230VAC	6A	over-current	1 NO point	n
CB6	Schneider iC65N-C20A/2P Vigi iC65 ELE	~230VAC	20A	over-current Leakage:30 mA	n	n
CB7	Schneider iC65N-D10A/4P iOF	~400VAC	10A	over-current	1 NO point	n
CB8	Schneider iC65N-D10A/4P iOF	~400VAC	10A	over-current	1 NO point	n
CB9	Schneider iC65N-C10A/2P iOF	~400VAC	10A	over-current	1 NO point	n

3.2.6.1.4 Power Distribution Cable List

The Power Distribution cable list is shown in Table 28.

Table 28: Cable list of Power Distribution

Cable No.	Description	Voltage	Current	Core Number	Outer Diameter	
W01	Power Supply from INFRA	~400VAC				provided by INFRA
W02	Protection Earth from INFRA	PE		1*16 mm^2	8 mm	provided by INFRA
W03	Power for DS Ancillaries	~230VAC	2A	2x1.0 mm^2	4 mm	
W04	Power for DS Pedestal Lights	~230VAC	1A	2x1.0 mm^2	4 mm	
W05	Power for Indexer	~400VAC	10A	4x1.5 mm^2	8 mm	
W07	Power for SPF Helium Compressor	~400VAC	10A	4x1.5 mm^2	8 mm	
W08	Power for Socket Outlet of Pedestal & Turnhead	~230VAC	2A	2x1.0 mm^2	4 mm	
W09	Power for PSC	~400VAC	50A	4 x10.0 mm^2	20 mm	
W10	PE for PSC	PE		1*16.0 mm^2	8 mm	
W11	Power PSC Power Distribution	~400VAC	50A	4 x10.0 mm^2	20 mm	
W12	PE for PSC Power Distribution	PE		1*16.0 mm^2	8 mm	
W13	Power for PSC Socket Outlet	~230VAC	2A	2x1.0 mm^2	4 mm	
W14	Power for HVAC	~400VAC	5A	4x1.0 mm^2	4 mm	
W15	Power for PSC Lights	~230VAC	1A	2x1.0 mm^2	4 mm	
W16	Power for UPS	~400VAC	40A	4 x10.0 mm^2	20 mm	Provide by MTM
W17	Power for EMISC	~230VAC	10A	2x1.5 mm^2	6 mm	Provide by EMISC
W18	Power for Servo Cabinet	~400VAC	40A	4 x10.0 mm^2	20 mm	Provide by MTM
W19	Power for SPF Band2	~230VAC	2A	2x1.0 mm^2	4 mm	
W20	Power for SPF Band345	~230VAC	2A	2x1.0 mm^2	4 mm	
W21	Power for SPF Band1	~230VAC	2A	2x1.0 mm^2	4 mm	
W22	Power for RXS Band123	~230VAC	2A	2x1.0 mm^2	4 mm	
W23	Power for RXS Band45	~230VAC	2A	2x1.0 mm^2	4 mm	
W24	Power for Indexer Socket Outlets	~230VAC	2A	2x1.0 mm^2	4 mm	
W25	Power for SPF Vacuum	~400VAC	5A	4x1.0 mm^2	4 mm	

3.2.7 Ventilation System

The Ventilation system consists of pedestal door inlet vent, PSC wave-guide inlet vent, PSC fans, PSC outlet wave-guide vent, turnhead outlet vent and the sunshield. The inlet air is filtered in two steps to ensure the inner environment of pedestal and the PSC.

The pedestal inlet vent is on the upper half of the pedestal door. It is a passive vent, consisting of rain-proof louver, insect-against mesh and air filter, as shown in Figure 172. The air filter meets the standard of EN 779 class G4. The dimensions are 600mm (width) * 600 mm (height) * 300mm (depth). The air filter and the insect-against mesh are designed as LRU for maintenance.

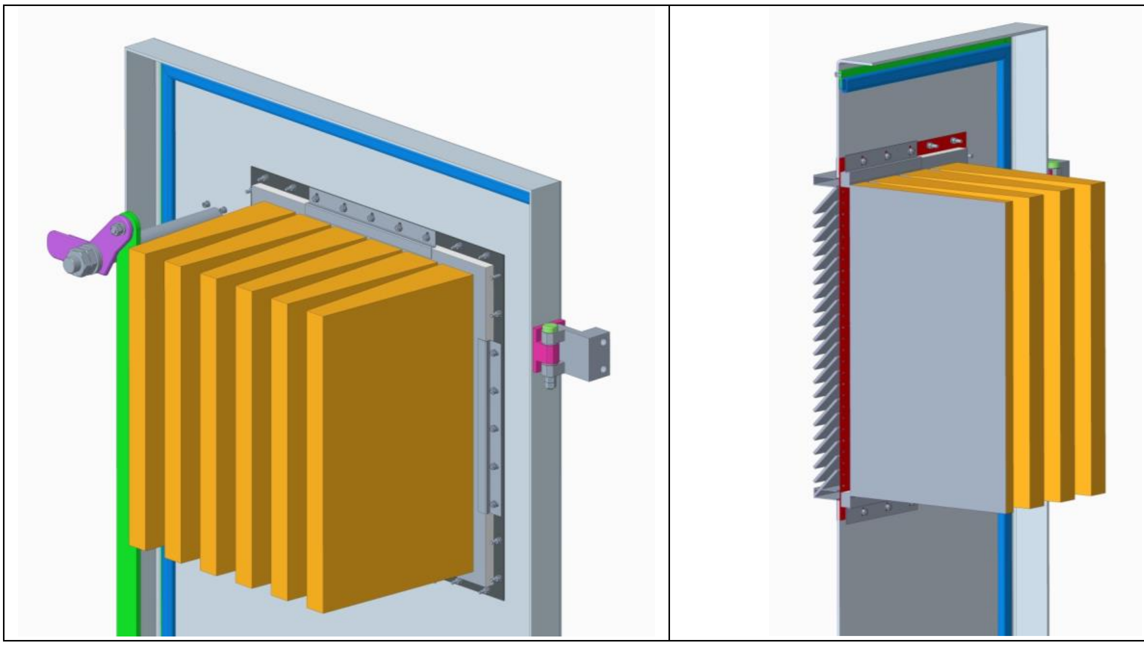
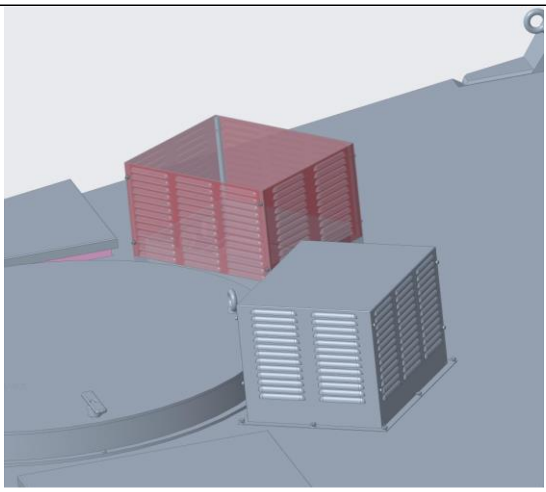
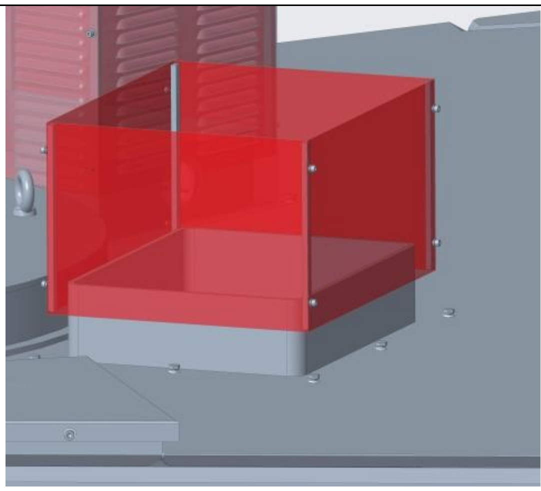


Figure 172: Ventilation window on the pedestal door

The double turnhead outlet vents are on the top of turnhead, beside the turnhead hatch. They are both passive vents with same section dimensions of 320mm*250mm. The turnhead outlet vents are equipped with insect-against filter and rain-proof cover as shown in Figure 173. The rain-proof cover is designed to prevent the rain and the splashed water from running into the turnhead.



a. rain-proof cover



b. Insect-against filter

Figure 173 Turnhead Ventilation

There are two PSC inlet wave-guide vents and two PSC outlet wave-guide vents, as shown in Figure 174. One of the PSC inlet vent is on the lower part of the PSC wall, beneath the EMISC. The other one is on the emergency hatch of PSC door, orientating to the drive cabinet. The two PSC outlet wave-guide vent, both on the PSC ceiling.

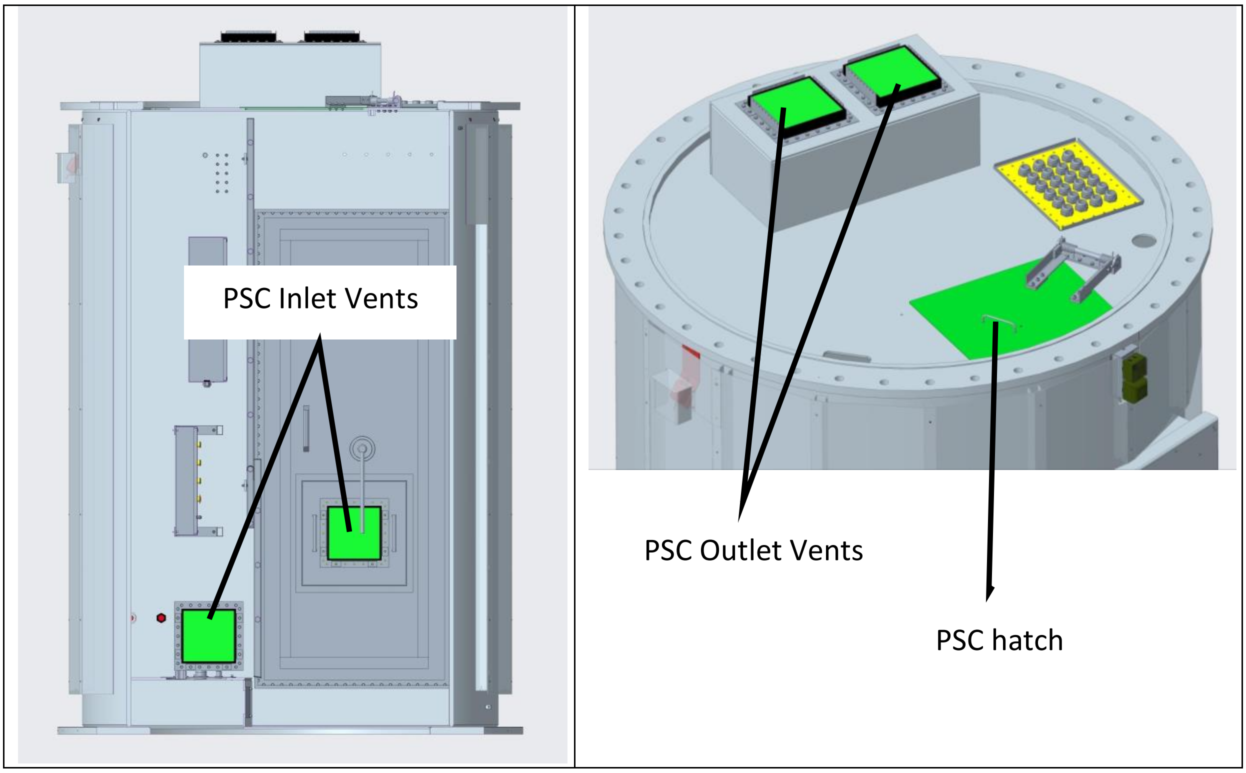


Figure 174 PSC inlet and outlet ventilations

The structures of PSC wave-guide vents are same. It consists of air filter, EMI wave-guide vent, and ventilation fan.

The air filter dimensions are 280mm*280mm*30mm, compliance with the standard of EN779 class G3. The EBMPAPST W2E 250-HL06-01 is selected as the ventilation fan, with the 250mm diameter vent area and 1865 m^3/h air flow. The air filters and fans are designed as LRU and easy replacement on site. the PSC fans can be switched off/on as required to conserve power and provide limited temperature stabilization between day and night

The inlet and outlet air flow inside the pedestal is separated by the hatch on the ceiling of lower section pedestal. The pedestal door is also equipped with rubber seal considering the outside environment.

The sunshield assembly is surrounding the lower section pedestal, as shown in Figure 175. It can prevent the solar heat load to increase the inner temperature of PSC. The sunshield is made of aluminium, composed of frame and plate. The frames are placed in vertical and the plates are opened at the bottom and top, providing the air ventilation channels around the pedestal wall.

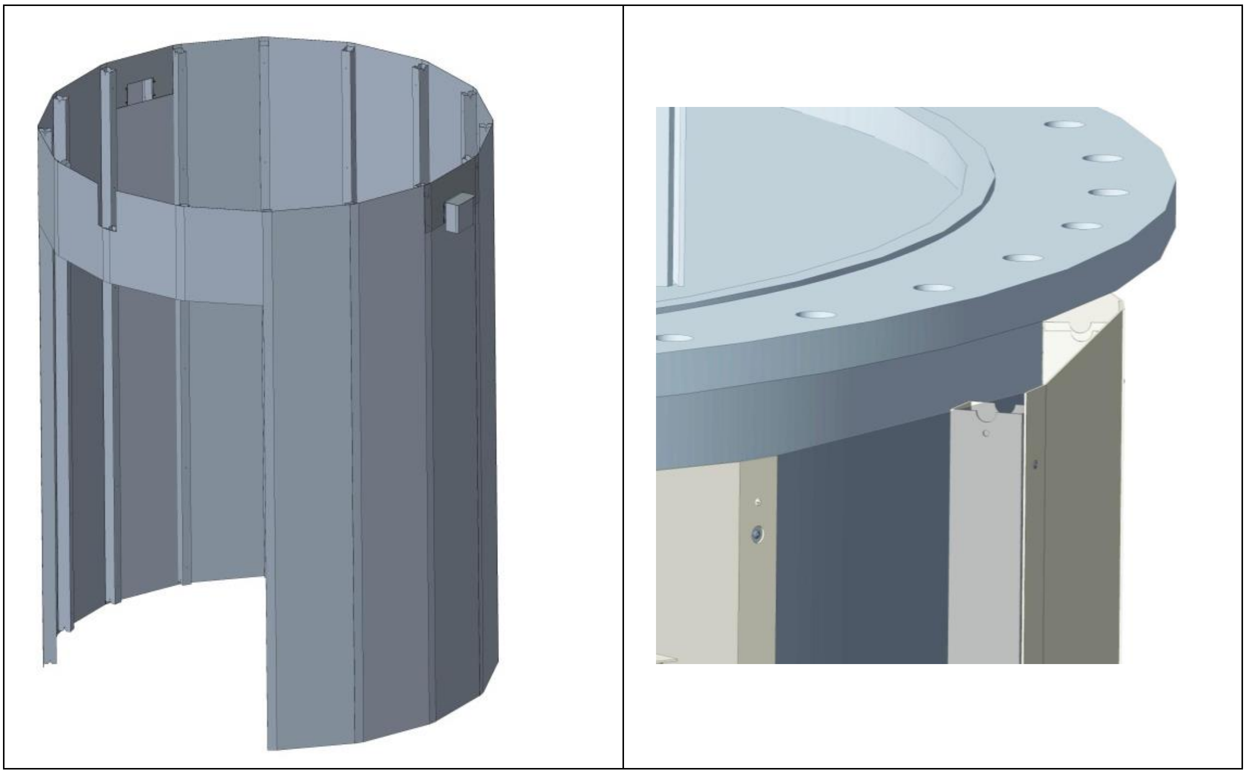


Figure 175: Sunshield around lower pedestal section

3.2.8 Lightning Protection

3.2.8.1 Design Base line

3.2.8.1.1 Technical regulation

- **Protection against lighting-Part 1:General principles (IEC62305-1: 2010, IDT)**
- **Protection against lighting-Part 2:Risk management (IEC62305-2: 2010, IDT)**
- **Protection against lighting-Part 3:Physical damage to structures and life hazard (IEC62305-3: 2010, IDT)**
- **Protection against lighting-Part 4: Electrical and electronic systems within structures (IEC62305-4: 2010, IDT)**
- **Standard for the Installation of Lightning Protection Systems (NFPA 780 2008 Edition)**
- **The wiring of premises Part 1:Low-voltage installations (SANS 10142-1:2008)**

3.2.8.1.2 Technical document

- **SKA-TEL-DSH-0000078 Lightning Protection System Requirements, Rev 2**
- **(SKA-TEL-SKO-0000115-Rev4).**

3.2.8.2 Lightning damage analysis

The lightning current damage on non-signal components is mainly the unbearable temperature rise caused by thermal effects. The lightning current damage on signal components is mainly due to the electromagnetic effects, which can result in cable short circuit and burning on inner-circuit of devices. The intensity of lightning current is considerable but the duration is quite short and the total energy is limited. After the lightning stroke on air termination, the current shall distribute and conduct though the whole dish steel structure. The thickness of steel air termination is larger than 4mm to prevent the hot spot. The required minimum section area of bonding between movable parts is $50mm^2$ to prevent the damage. The distributed current shall be too small to cause the mechanical damage.

During the lightning conducting, the temporary electromagnetic field shall be generated, leading to the induced surge current on the device cable and then damage the device interface. In addition, the temporary high electric potential can induced on the metal housing at high position, while the cable core has low electric potential as being connected to lower position device. The voltage difference between cable interface and housing can damage the insulation and device. The surge protection devices are applied to protect electronic equipment. For equipment that is not suitable for surge protection device, the equipotential connection shall be applied on the housing or casing

The lightning protection design is followed with the lightning protection system analysis in the RD[](SKA-TEL-DSH-0000078). For the dish structure, the lightning parameters are given by the IEC 62305 LPL Ⅲ, as shown in Table 29, Table 30 and Table 31.

Table 29 Maximum current levels (relating to sizing efficiency) for LPL I to IV and probability of exceeding these levels.

	LPL I	LPL II	LPL III	LPL IV
Maximum peak current (kA 10/350us)	200	150	100	100
Probability current is greater (%)	1	2	3	3

Table 30 Minimum current levels (related to interception efficiency) for LPL I to IV

	LPL I	LPL II	LPL III	LPL IV
Minimum current (kA)	3	5	10	16
Probability current is greater than minimum (%)	99	97	91	84
Rolling sphere radius (m)	20	30	45	60

Table 31 Class of LPS and Lightning Protection Level (LPL)

Class of LPS	Lightning Protection Level (LPL)
I	I (highest)
II	II
III	III
IV	IV

Based on the risk assessment and the above information, the SKA1 DSH Element LPS must be designed to LPL III.

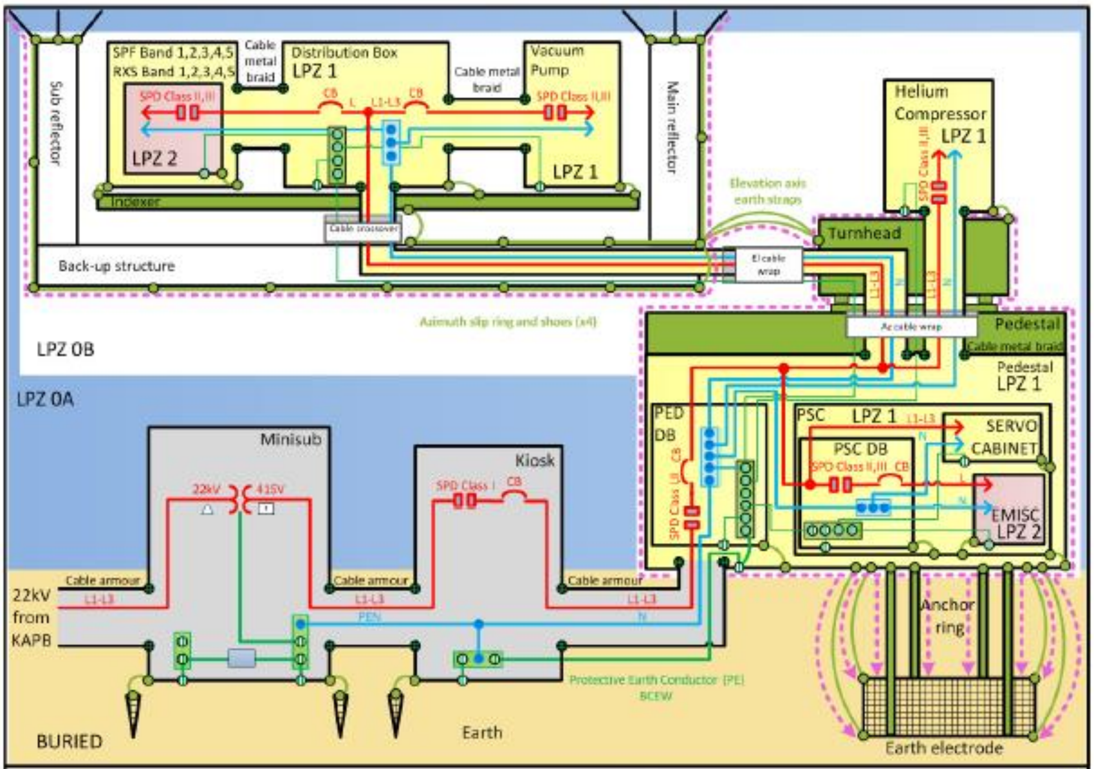
3.2.8.3 Lightning Protection Zones

Lightning protection zones (LPZ) are used to define the electromagnetic environment, as shown in Table 32.

Table 32: Lightning Protection Zone Definition

LPZ	Exposure Threats		
	Lightning Flash	Lightning Current or Induced Current	Electromagnetic Field
LPZ 0A	Yes	Full	Full
LPZ 0B	No	Partial	Full
LPZ 1	No	Limited	Partial
LPZ 2	No	Reduced below LPZ 1	Reduced below LPZ 1

The suggested SKA1 MID DISH element LPZs is shown in Figure 176.



SCHEMATIC SYMBOL KEY	
	Earth Electrodes. The rectangle includes the concrete plate reinforcement (mats and rods), and a closed ring of tinned copper wire connected at regular intervals around the circumference of reinforcement. The earth system for the triangle is not known.
	Earth bars found inside a distribution box. Green = Protective Earth bar. Blue = Neutral Earth bar.
	Indicates a symbolic split of the 3 phase (L1-L3) or 1 phase (L) Live wire(s). Refer to the Power Management document (SKA-TEL-DSH-0000041) for the power distribution diagram. Protective Earth galvanic connection to a shielded enclosure or earth bar. Regular connection to Lightning Protection Earth (Common Bonded Network). Neutral galvanic connection. 360° Galvanic connection between a shielded line (cable armour or cable metal braid) and a shielded enclosure. Lightning Protection Earth galvanic connection to a shielded enclosure, earth strap, dish structure, air terminal or earth electrode.
	Lightning Protection Earth wire: 1) Refer to SANS 62305-3 Table 6 for material, configuration and minimum cross-sectional area of the air termination rods and down conductors on the primary down conductor path (next to the dashed pink trace). 2) Refer to SANS 62305-4 Table 1 for minimum cross-sections of the bonding components not on the primary conducting path (wires that are not next to the dashed pink trace). Protective Earth wire / straps – 4mm² insulated copper. PE to be bonded to the inside of a shielded enclosure to protect humans against electrical shock (TN-S). Neutral wire (N). Live wire(s). 3 phase (L1-L3) or 1 phase (L).
	Primary lightning current conduction path from direct lightning strike.
	Surge Protection Device. Minimum Class 1 (or Class 1 & Class 2) required at DISH entrance to protect against lightning surges on services. Additional Class 2 (or Class 3) required at Zone 2 boundary. In TN-S system, L1-L3 and N connected to Lightning Protection Earth through SPD. PE direct bond to Lightning Protection Earth or through SPD. SPD ratings to be coordinated.
	55:1 Transformer.
	Circuit breaker. To protect the DISH electrical installation, (wires etc.) against overcurrent from equipment. Circuit breaker ratings to be coordinated.

ZONE AND AREA DEFINITION	
External Dish Structure in LPZ 0B not used for Lightning Protection Earth. Bonding to Lightning Protection Earth required to prevent sparking.	LPZ 0A. The DSH Element air terminals does not protect this area from direct lightning flashes.
External Dish structure in LPZ 0B used for Lightning Protection Earth. Lightning currents will flow in these parts of the structure – Refer to Table 3 of SANS 62305-3 for minimum thickness (t) for structure.	LPZ 0B. The DSH Element air terminals protects this area from direct lightning flashes.
LPZ 1. Black frame indicates the zone boundary and is typically a shielded enclosure or shielded line (cable armour or cable metal braid). Where the LPZ1 borders on LPZ0B, refer to Table 3 of SANS 62305-3 for minimum thickness (t') for shields.	Soil. All equipment in this area is buried.
LPZ 2. Black frame indicates the zone boundary and is typically a shielded enclosure or shielded line (cable armour or cable metal braid).	Unknown Lightning Protection Zone.

ACRONYMS AND ABBREVIATIONS	
BCEW	Bare Copper Earth Wire
CB	Circuit Breaker
EMISC	EMI Shielded Cabinet
KAPB	Karoo Array Processing Building
LPZ	Lightning Protection Zone
PE	Protected Earth
PED	Pedestal
PSC	Pedestal Shielded Compartment
SPD	Surge Protection Device

Figure 176: SKA1 MID DISH Lightning Protection Zones

3.2.8.4 External Lightning Protection System

3.2.8.4.1 Over view diagram

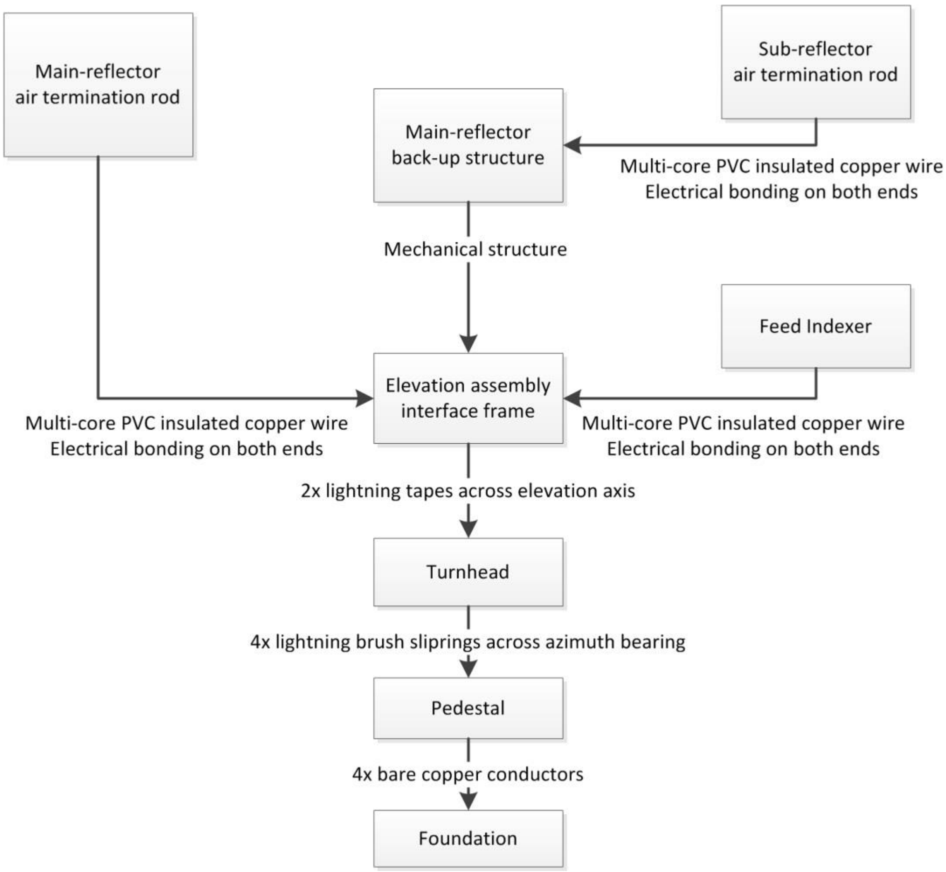


Figure 177 Overview Diagram of the Down Conductor System

The Overview diagram of the down conductor system is shown in Figure 177. Each parts will be described as below. The bare copper conductors and foundation system is referred to the INFRA ICD (SKA-TEL-SKO-0000115-Rev4).

3.2.8.4.2 Air termination

3.2.8.4.2.1 Air termination rod

Five air-termination rods will be mounted on the backup structure of main-reflector and two rods will be mounted on sub-reflector knots. The rods are made of stainless steel with diameter of 25mm and lengths from 1m to 1.8m.
The air termination rod will be connected with the knots of backup structure and will be electrically bonded with down conductor wire. The down conductor wires will be electrically connected to the elevation assembly interface, which is then bonded with turnhead with copper tape.

3.2.8.4.2.2 Main-reflector backup structure

The backup structure of main reflector can be considered as additional part of air termination system, which can protect the device, cable, fibre and other non-metal components within the protection range.
According to the IEC62305-3(2010)-5.1.3, the permanent conductive components may be used as parts of LPS.

5.1.3 Use of natural components

Natural components made of conductive materials, which will always remain in/on the structure and will not be modified (e.g. interconnected steel-reinforcement, metal framework of the structure, etc.) may be used as parts of an LPS.

Other natural components can only be considered as being additional to an LPS.

3.2.8.4.2.3 Air termination protection range

The air termination protection range is shown in Figure 178 and Figure 179.
The sphere ball 3D check has been perform, of which one interested case is shown in Figure 180.

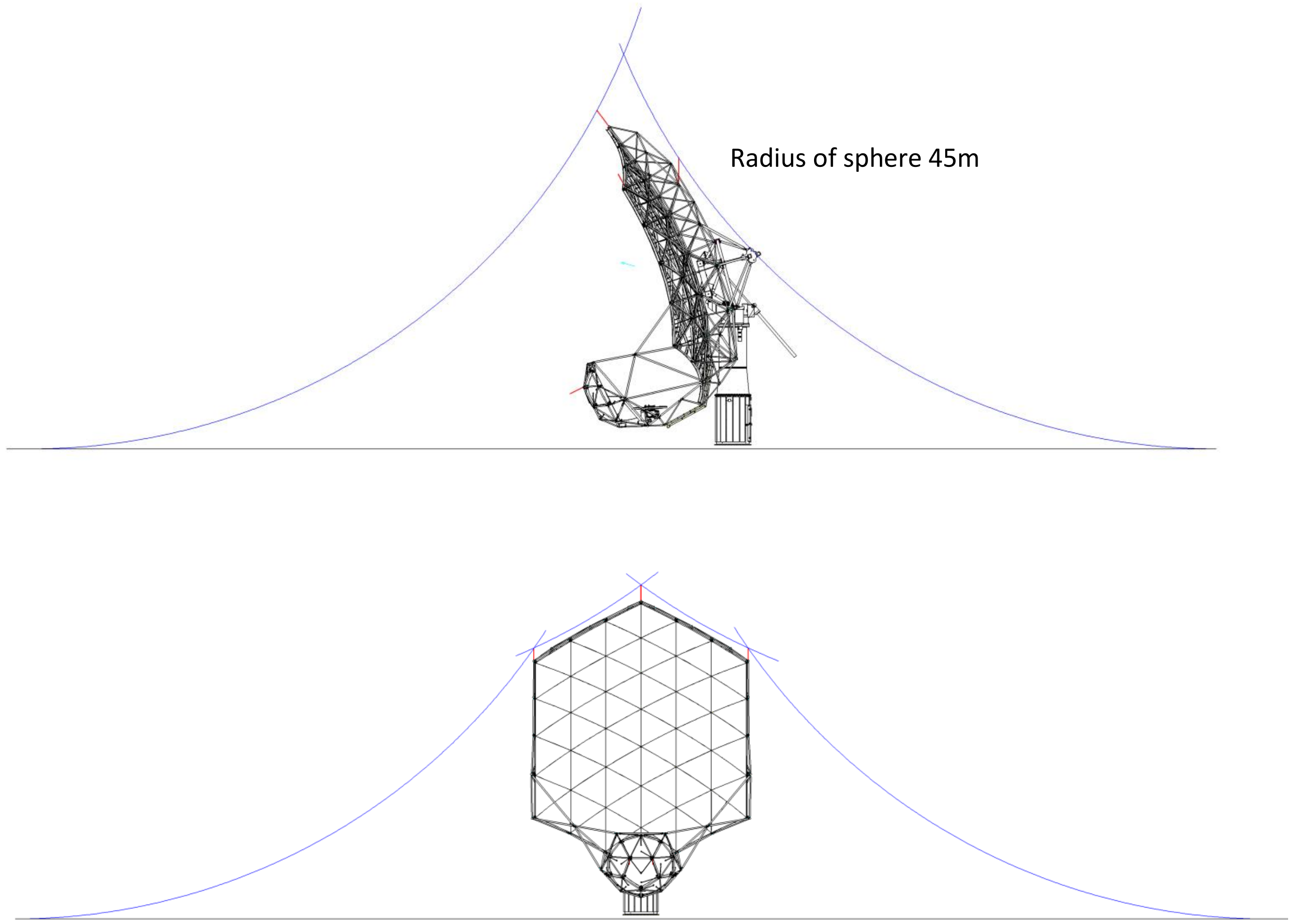


Figure 178 Air Termination Protection Range (Elevation angle=15°)

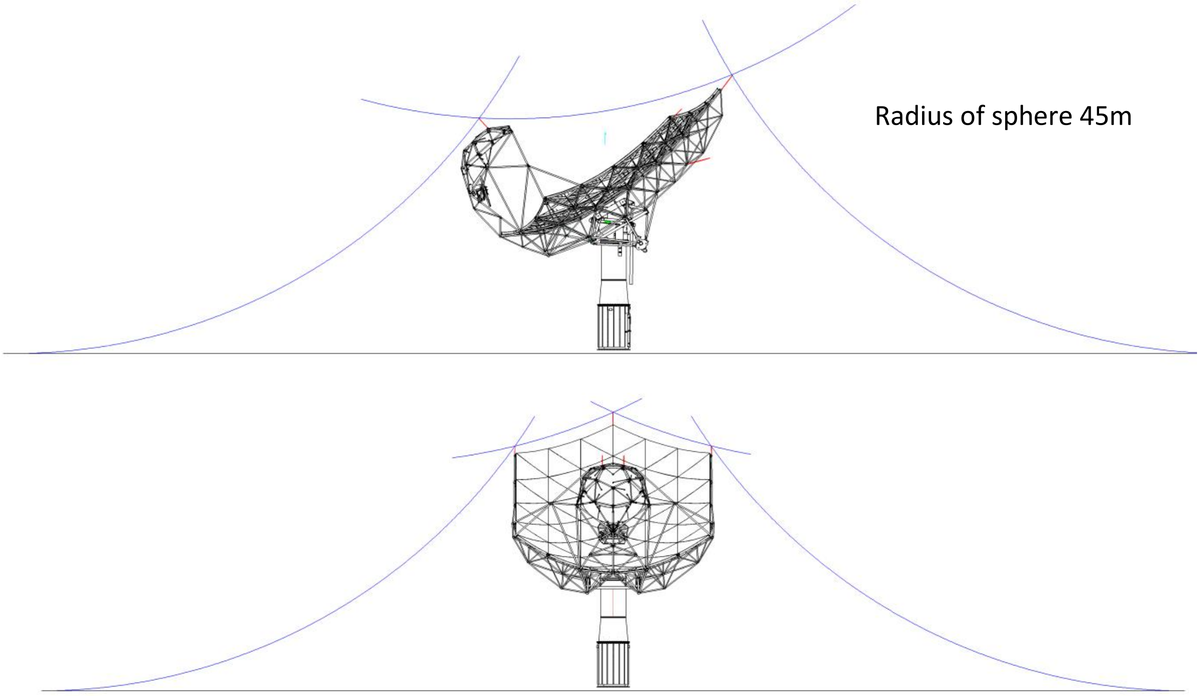


Figure 179 Air termination Protection Range (Elevation Angle=90°)

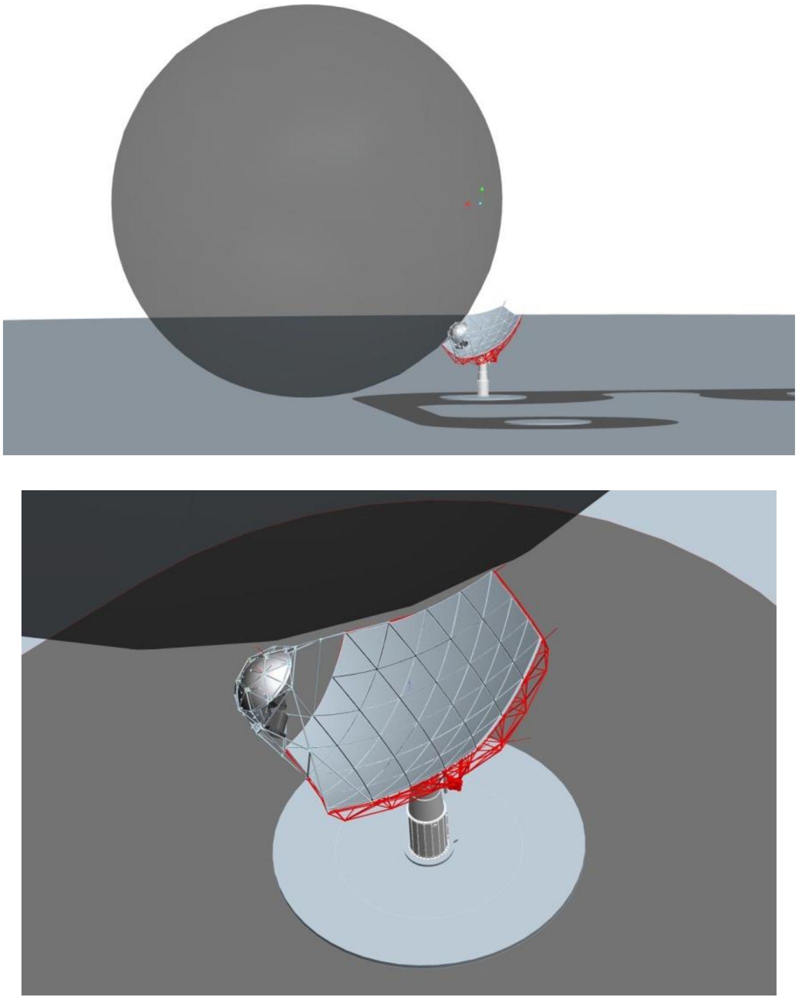


Figure 180 Sphere Check of Side Contact (Elevation Angle=15°)

3.2.8.5 Down-conductor system

3.2.8.5.1.1 Natural down conductors

According to IEC62305-3:2010-5.3.5, the components of dish structure may be considered as down conductors, shown as followed:

5.3.5 Natural components

The following parts of the structure may be used as natural down-conductors:

a) the metal installations provided that

– the electrical continuity between the various parts is made durable in accordance with 5.5.3,

– their dimensions are at least equal to that specified in Table 6 for standard down-conductors.

Piping carrying readily-combustible or explosive mixtures shall not be considered as a down-conductor natural component if the gasket in the flange couplings is not metallic or if the flange-sides are not otherwise properly bonded.

NOTE 1 Metal installations may be clad with insulating material.

b) the metal of the electrically-continuous reinforced concrete framework of the structure;

NOTE 2 With prefabricated reinforced concrete, it is important to establish interconnection points between the reinforcing elements. It is also important that reinforced concrete contains a conductive connection between the interconnection points. The individual parts should be connected on-site during assembly (see Annex E).

NOTE 3 In the case of pre-stressed concrete, attention should be paid to the risk of causing unacceptable mechanical consequences, due either to lightning current or as a result of the connection to the lightning protection system.

c) the interconnected steel framework of the structure;

NOTE 4 Ring conductors are not necessary if the metal framework of steel structures or the interconnected reinforcing steel of the structure is used as down-conductors.

d) the facade elements, profile rails and metallic sub-constructions of facades, provided that

– their dimensions conform to the requirements for down-conductors (see 5.6.2) and that for metal sheets or metal pipes thicknesses shall be not less than 0,5 mm,

– their electrical continuity in a vertical direction conforms to the requirements of 5.5.3.

NOTE 5 For more information, see Annex E.

Table 6 – Material, configuration and minimum cross-sectional area of air-termination conductors, air-termination rods, earth lead-in rods and down-conductors[a]

Material	Configuration	Cross-sectional area mm²
Copper, Tin plated copper	Solid tape	50
	Solid round[b]	50
	Stranded[b]	50
	Solid round[c]	176
Aluminium	Solid tape	70
	Solid round	50
	Stranded	50
Aluminium alloy	Solid tape	50
	Solid round	50
	Stranded	50
	Solid round[c]	176
Copper coated aluminium alloy	Solid round	50
Hot dipped galvanized steel	Solid tape	50
	Solid round	50
	Stranded	50
	Solid round[c]	176
Copper coated steel	Solid round	50
	Solid tape	50
Stainless steel	Solid tape[d]	50
	Solid round[d]	50
	Stranded	70
	Solid round[c]	176

[a] Mechanical and electrical characteristics as well as corrosion resistance properties shall meet the requirements of the future IEC 62561 series.

[b] 50 mm² (8 mm diameter) may be reduced to 25 mm² in certain applications where mechanical strength is not an essential requirement. Consideration should in this case, be given to reducing the spacing between the fasteners.

[c] Applicable for air-termination rods and earth lead-in rods. For air-termination rods where mechanical stress such as wind loading is not critical, a 9,5 mm diameter, 1 m long rod may be used.

[d] If thermal and mechanical considerations are important then these values should be increased to 75 mm².

3.2.8.5.1.2 Down conductor cable & point

Type: BVR-70
Core diameter: 70mm^2
Multi-core PVC insulated copper wire
Bending radius: >100mm
Bonding requirements: Stainless steel cable lug terminal bonded with bolt

3.2.8.5.1.3 Sub element electrical connection

The resistance between a sub-element earth connection point and the foundation ring shall be less than 0.2Ω. The sub-element shall be electrically bonded with main steel dish structure, for example as followed:

a) Indexer equipment: metal house bonded with indexer by earth straps
b) Azimuth actuator: metal cover bonded with gearbox house by mechanical connection
c) Elevation actuator: actuator house bonded with turnhead by earth strap

d) SPFHe Compressor: compressor house bonded with bracket & turnhead by mechanical connection and earth strap
e) Sub-reflector: For each sub-reflector panel, an aluminium plate is attached onto the side of the panel. The metallization is performed on the reflecting surface as well as the side so that the equipotential connection between all the sub-reflector panels can be achieved via the aluminium plate and the connection cables.
f) Main-reflector panel: The skin of main reflector will be electrically connected with back ribs with rivets.

3.2.8.5.1.4 Movable part electrical connection

The soft connecting wire and slip ring brush are applied to connect movable components. The cylinder or tape conductor can be used for soft connecting wire. The section area of cylinder conductor shall no less than $50mm^2$, and the section area of tape conductor shall not less than $50mm^2$ with thickness no less than 2mm.

(a) Indexer
The rotational part of indexer will be equipped with a lightning earth cable, which shall be routed inside the indexer cable wrap and connected to down conduct system of sub-reflector.

(b) Elevation axis
Dual flat copper braided tapes are applied between the elevation assembly interface frame and the turnhead, as shown in Figure 181. The section dimensions of each tape are 3mm*60mm. Two ends of the tape are electrically connected to the steel structure.

(c) Azimuth bearing
Four slip ring brushes are applied between the inner ring of azimuth bearing and the pedestal structure, as shown in Figure 182. The section dimensions of copper tape are 3mm*30mm.The slip ring brush is electrically bonded with pedestal steel structure and contacted with inner ring of azimuth bearing by an aluminium bronze contactor. The contact area for single block is 1200mm2. The aluminium bronze is used for contact material as it is harder to be welded.

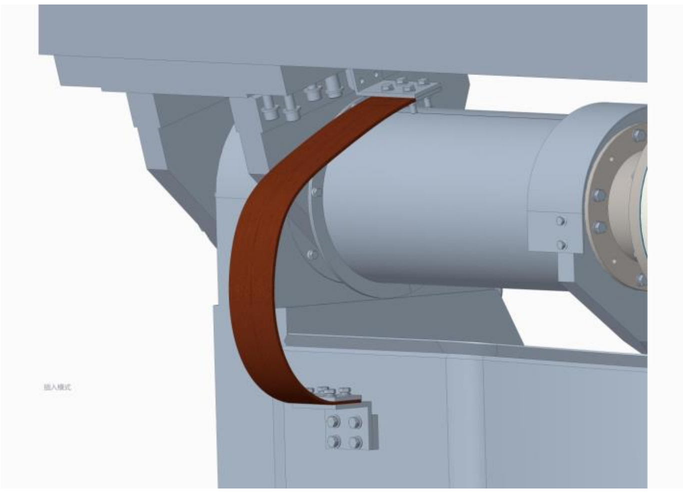


Figure 181 Elevation Bearing Lightning Strap

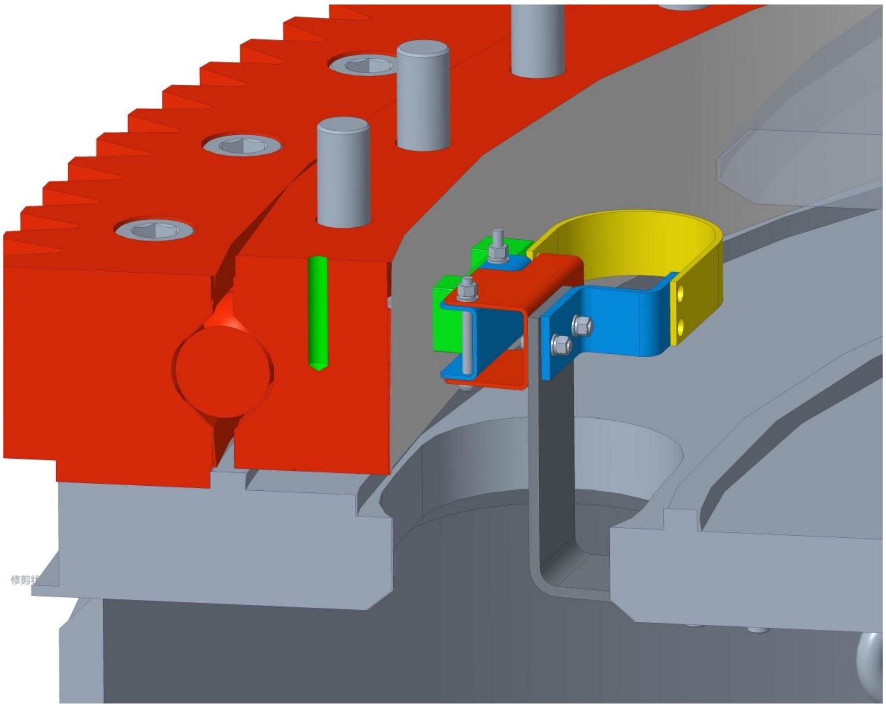


Figure 182: Azimuth Bearing Lightning Slip Ring Brushes

3.2.8.5.1.5 Analysis

(1) Resistance

Based on the engineering experience, the bonding resistance of main-reflector antenna main steel structure can be lower than 0.02Ω. The bonding resistance between the sub-reflector air termination rod and the main-reflector back-up structure can be achieved lower than 0.03Ω using tightened bolts. The resistance can be measured using the milliohm meter (equipotential measuring instrument).

(2) Material

The copper tape is applied for the down-conductor device at the elevation axis and azimuth bearing. The copper has advantages in corrosion resistance, conductivity and service life, which is suitable for low maintenance cost for dish array.
The stainless steel is used for the cable lug. Considering the electrochemical corrosion between the copper wire and steel structure when lightning current goes through, the stainless steel lug is used due to the electrochemical potential between copper and steel.

(3) Sparking inside cable screen

The sparking inside cable screen means that the unbearable temperature rising occurs internal insulation of the cable.
According to IEC62305-3:2010, the calculation is given as following,

$$I_f = 8 \times SC$$

Where:
I_f: in kA, the total lightning current through cable screening layer (or metal tube with interior unscreened cable).
SC: in mm^2, section area of cable screening layer or metal tube.
The cable screening layer and metal tube will be checked to avoid the sparking.

3.2.8.6 Internal lightning protection devices

3.2.8.6.1 Surge protection device

The surge protection devices are illustrated in the section of power distribution. The specifications are shown as followed.

(1) One set of SPD class Ⅰ test is equipped at the inlet of pedestal power distribution box. One set of small air circuit breaker is equipped at the frontend of the SPD class Ⅰ test. The specifications of SPD class Ⅰ test and the air circuit breaker are shown as followed.

SPD class Ⅰ test

- Impulse current (I_{imp}): 25kA (10/350µs)
- Voltage protection voltage(U_p):≤2.5kV
- Maximum continuous operating voltage (U_C)L-N, N-PE, 275V; suitable for 3-phase power
- Shell insulation: >100MΩ
- Cut-off power-flow current: 3kA
- Length of cable to the frontend air circuit breaker 0.5m with no less than 10mm^2 cable section area
- Length of earth cable 0.5m with no less than 25mm^2 cable section area

Air circuit breaker

- Nominal current: 63A
- Operation voltage: AC400V
- Fault current cut-off time: less than 1s

(2) One set of SPD class Ⅱ test is equipped at the inlet of pedestal shielding compartment power distribution box. One set of small air circuit breaker is equipped at the frontend of the SPD class Ⅱ test. The specifications of SPD class Ⅱ and the air circuit breaker are shown as followed.

SPD class Ⅱ test

- Maximum discharge current (I_{max}): 40kA (8/20µs)
- Nominal discharge current (In): 20kA (8/20µs)
- Voltage protection voltage(Up): ≤1.5kV (10kA, 8/20µs)
- Maximum continuous operating voltage (U_C): L-N, N-PE, 385V
- Shell insulation: >100MΩ
- Leakage current: ≤20µA (0.75U_{1mA})
- Length of cable to the frontend air circuit breaker 0.5m with no less than 6mm^2 cable section area
- Length of earth cable 0.5m with no less than 16mm^2 cable section area

Air circuit breaker

- Nominal current: 32A
- Operation voltage: AC400V
- Fault current cut-off time: less than 1s

3.2.8.6.2 Shielding

To fulfil the requirements of R.DS.LPS.8, 9, 10 for DS lightning protection zone 1&2, the requirements are stated as following:

(1) The cable between relative devices shall be routed inside the metal tube/tray or screened cable should be used. The device with non-metal house shall be mounted inside metal case. The screening layer, tube and tray must be electrically continued, and the ends should be electrically bonded with metal house or metal case of the device. The resistance between any metal point on the dish structure and the foundation ring shall be no more than 0.2Ω.

(2) The joint point of screening tube and tray must be electrically continued and the resistance

between any two points on the dish structure shall be no more than 0.2Ω.

(3) The material of screening tube and tray should be hot dip galvanized. Based on the Annex B of IEC62305-3:2010, the thickness of tube shall be no less than 0.5mm and the thickness of the tray plate should be no less than 1mm.
(4) The metal screened cable will be applied for power supply of helium compressor. The metal screening layer will be bared and connected to helium compressor housing and turnhead structure at the connection or penetration points via specified EMI 360 connector.
(5) The cables of azimuth actuator shall be screened. The metallic cable conduits are applied to house the servo cables for two azimuth actuator. The conduits will be electrically connected with the turnhead outlet cable box and the azimuth motor steel covers.
(6) The cables of elevation actuator shall be screened. Two metallic cable conduits are applied to house the servo cables for elevation actuator. The conduits are electrically connected with the turnhead outlet cable box and the elevation actuator metallic cable box.
(7) The cables of elevation I/O unit shall be screened. Two metallic cable conduits are applied to house the servo cables for elevation I/O unit. The conduits are electrically connected with the turnhead vent box and the elevation I/O unit box.
(8) The cables of indexer actuator shall be screened. Three metallic cable conduits are applied to house the servo cables for Indexer actuator and Indexer I/O unit. The conduits are electrically connected with the elevation assembly cable tray and the Indexer actuators metallic cable box and the Indexer I/O unit box.

3.2.8.6.3 Equipotential bonding

All the metal house, metal case, metal tube, metal tray, cable screen layer should be equipotentially bonded with nearest dish steel structure. The section area of conductor shall be no less than 16mm^2. The thickness of tape conductor shall be no less than 2mm. The resistance between any two points on the dish structure shall be no more than 0.2Ω.

3.2.9 Azimuth Cable Wrap

As shown in Figure 183, the azimuth cable wrap applies the steel-wire dual hanging rings structure. The azimuth cable wrap consists of inner rings, outer rings, rotating shaft, sliding sleeve and fixture. The inner rings are hung to the rotating shaft through several steel wires. The inner ring on the top is fixed to the rotating shaft, as the hanging point for the rest inner rings. The steel wires extend to the outer rings structure. Similarly, the outer rings are hung to the fixture that is mounted on the ceiling of the upper section pedestal via those steel wires. The outer ring on the top is fixed to the fixture as the hanging point for the rest outer rings.

The sliding sleeve is attached with the lowest inner and outer rings, forming a rigid body. With constrains of the rotating shaft, only the rotation and axial motion along the azimuth axis are allowed for this rigid body.

The cables and fibre conduits will be attached to the inner rings and outer rings via quasi-hinge joints. The gravity and torque force are borne by steel wire. When the turnhead is rotating, the rings are rotating and going up & down, show in Figure 184. The rotation angle will be distributed via relevant rotation movement between the neighbouring rings. The wrapping range of azimuth cable wrap is +270˚ to -270˚. The length of cable over the azimuth cable wrap is about 4 meters, resulting in the maximum twisting angle of 70˚ per meter

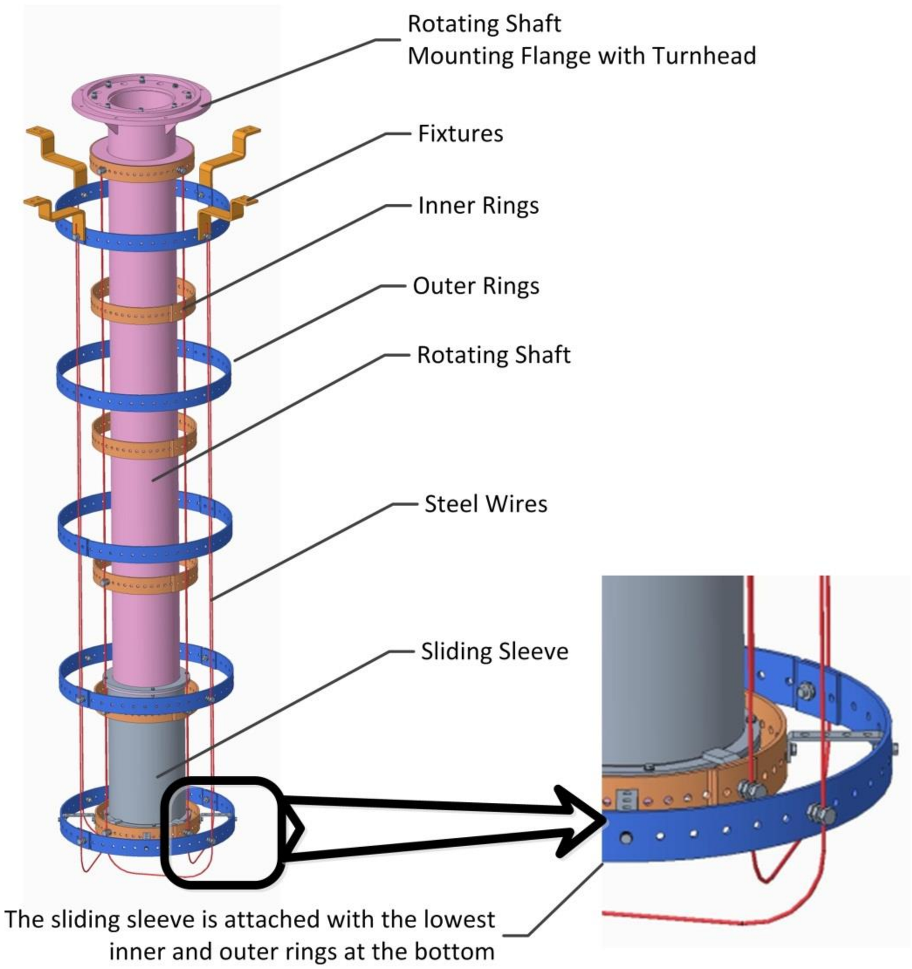


Figure 183: Azimuth Cable Wrap Overview

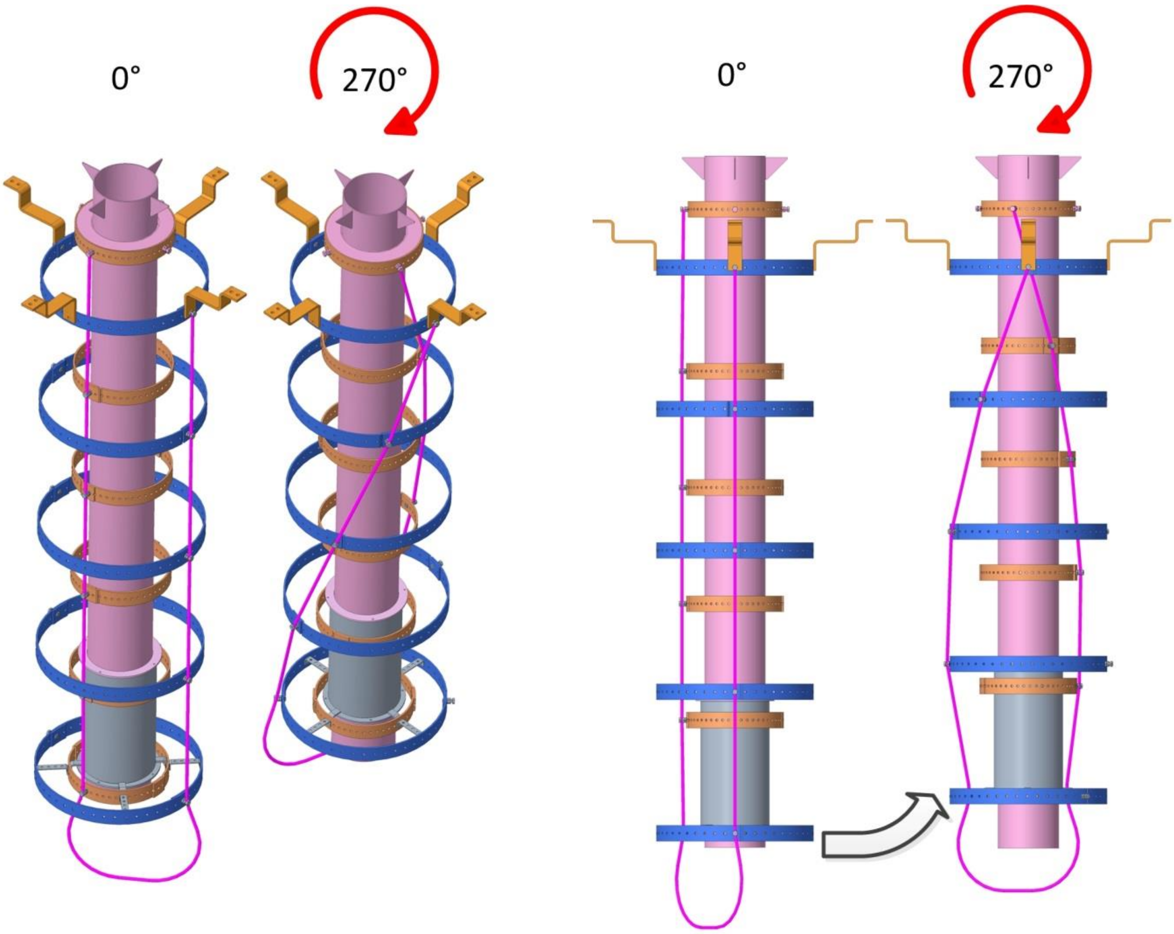


Figure 184: Azimuth Cable Wrap Rotating Pattern

3.2.10 Elevation Cable Wrap

The elevation cable wrap is mounted between the middle front of the turnhead and the elevation assembly interface frame, as shown in Figure 185. The straight steel cable wrap is selected, type AG 100 III 250 R250-1000.

The total length of the cable wrap is 10x100mm=1000mm. The inner section is frame type and the area is 55mm*250mm. The patterns of the cable wrap at two end elevation angles are shown in Figure 186 and Figure 187. The outlet of the cable wrap inside turnhead is slightly "uphill", which can prevent the water from going into the turnhead

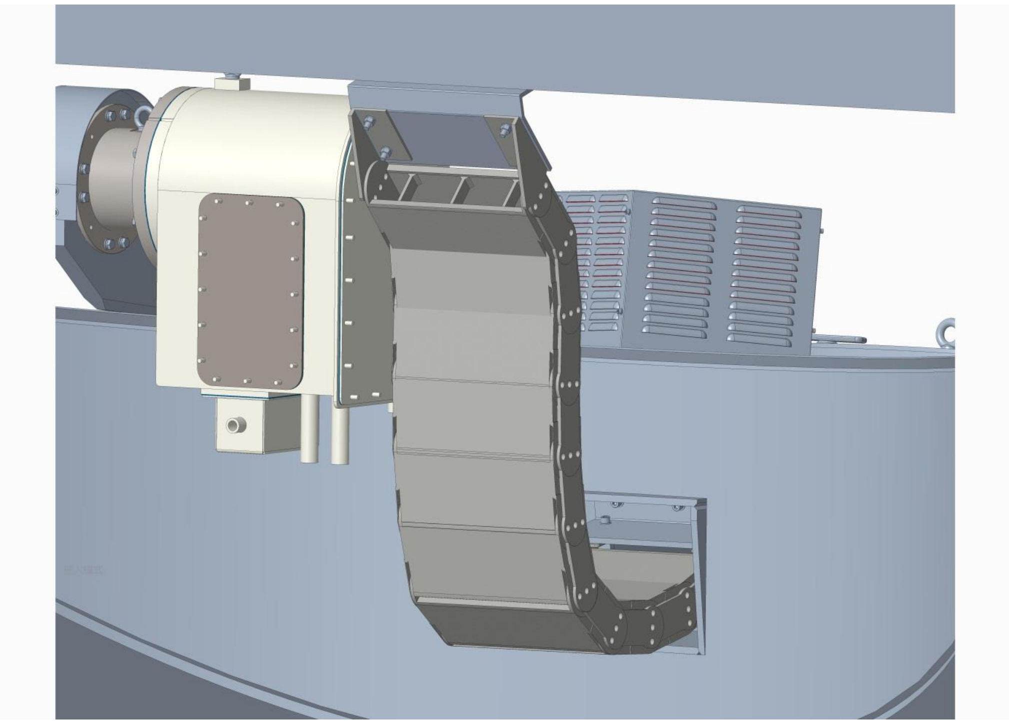


Figure 185 Elevation Cable wrap

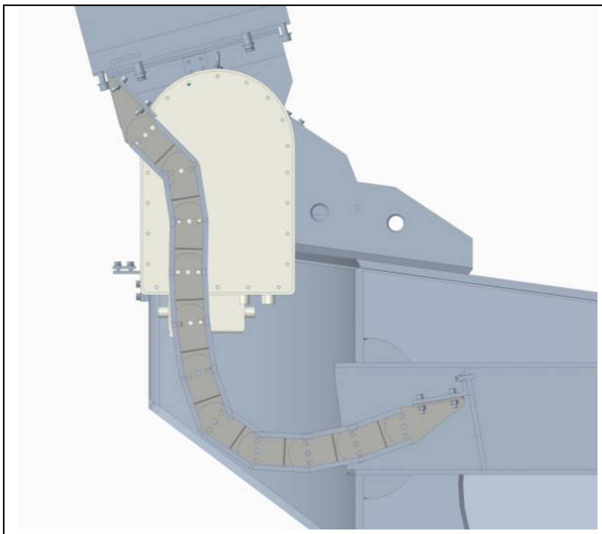
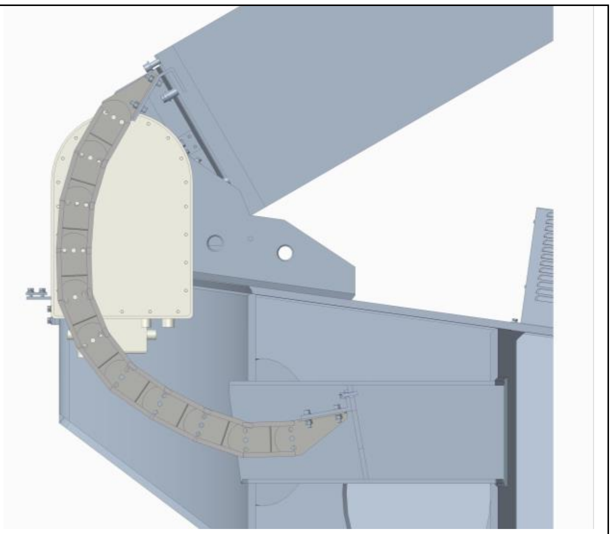
	

Figure 186: Elevation cable wrap at EL=15°	Figure 187: Elevation cable wrap at EL=90°

The minimum radius of elevation cable wrap is 250mm. But there are only few chain units can reach the limit positions. The inner cable bending radius check of cable wrap at the worst case, end position of EL=15°, shown as Figure 188:

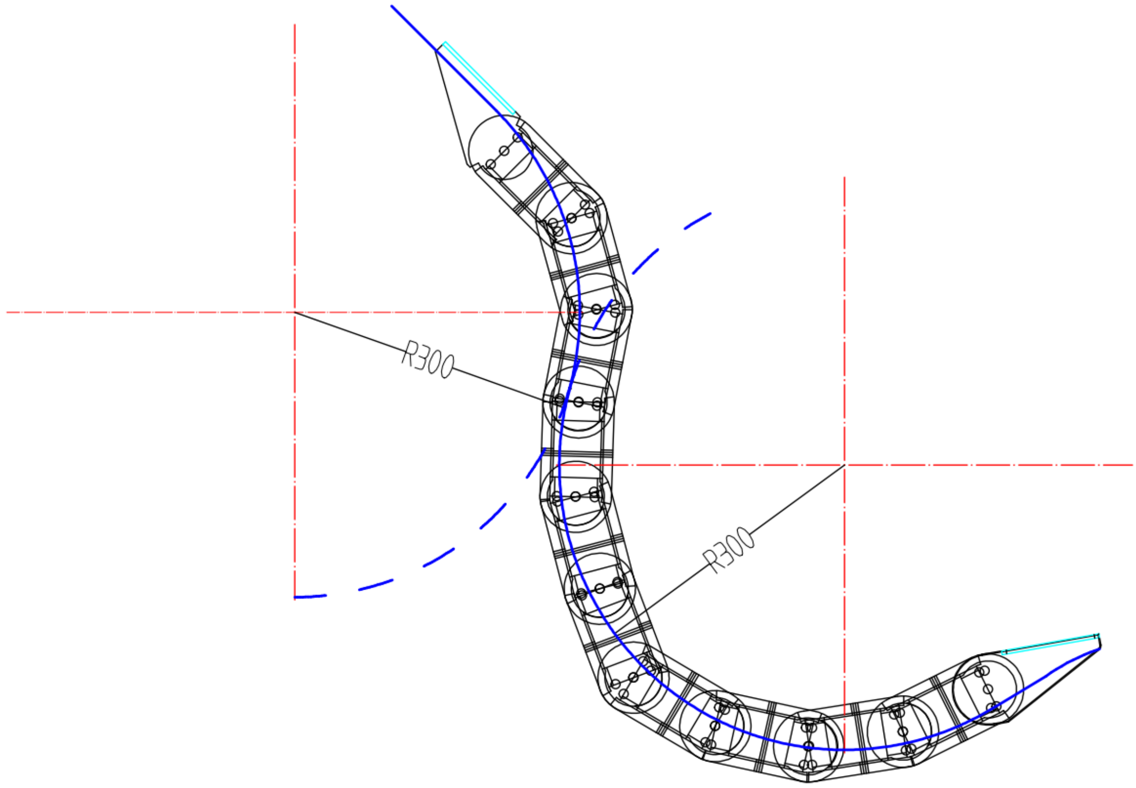


Figure 188: The inner cable bending radius check of elevation cable wrap at EL=15°

The elevation cable wrap is made of steel to ensure the conductive enclosure for lightning protection.

3.2.11 Cable Ducting

3.2.11.1 Foundation Cable Entry

The interface of cable from foundation to pedestal is focused on the conduit positions, cables list and allocation. The cable entry from foundation to pedestal is show as Figure 189.

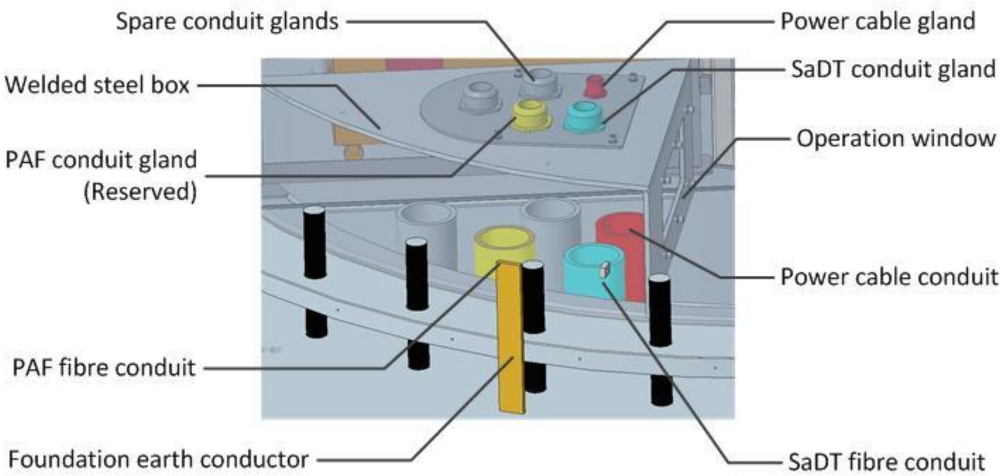


Figure 189: Foundation Cables Entry

The cables from foundation to pedestal pass through a welded steel box. Considering that the conduit is difficult to locate, the floor of pedestal around the conduits is opened to give sufficient clearance for conduits.
The conduits ends are above the pedestal floor and lower than operation window. The lid of cable entry box is bolted and can be lifted to install the cables. The operation window can be removed to give more operation space.
According to interface drawing, one power cable is connected to pedestal power distribution through the red gland and the cable armouring will be conducted with the gland as well. The other two fibre cables are connected to the fibre patch panel on the second floor of pedestal and then distributed to different parts.
The M12 bolts and D12 washers are applied to connect the power earthing conductor. The earthing conductor can then be connected to pedestal power box. The welded structure ensures that the resistance meets the requirement. The power earth conductor to be connected to the steel structure as well.

3.2.11.2 Pedestal Inside Cable Routing

The overview of cable routing inside the pedestal is shown as Figure 190, Figure 191, and Figure 192. The cables and fibres is attached with the stainless steel cable tray, which has been mounted before the delivery.

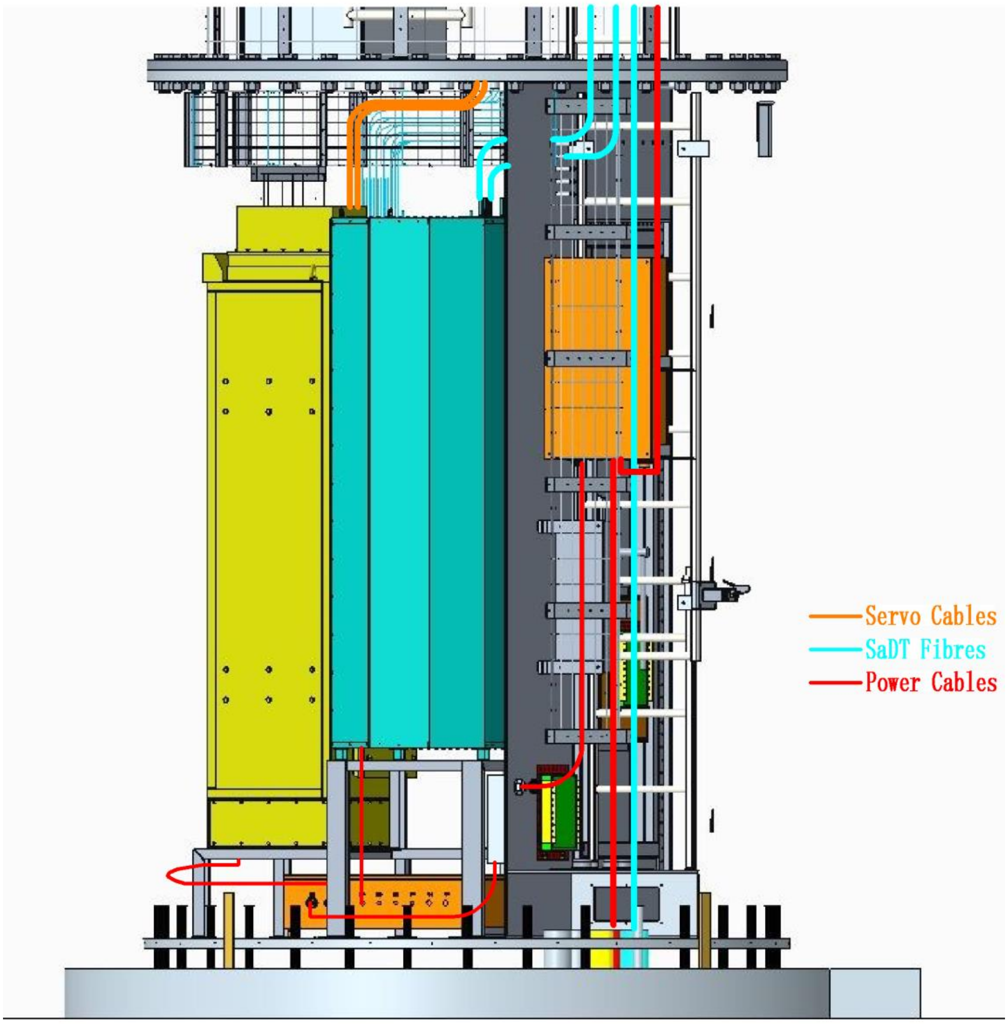


Figure 190: Cable Ducting in Lower Pedestal Section

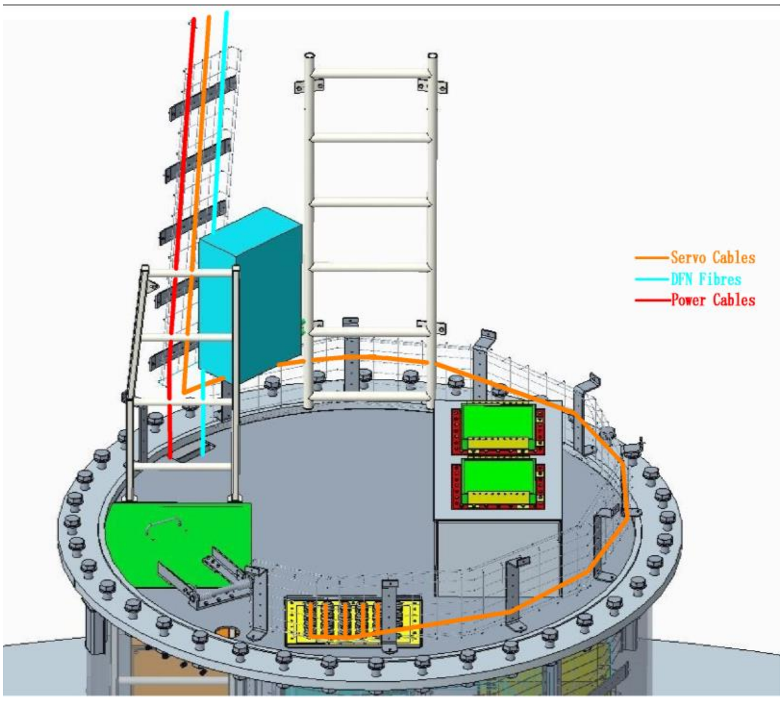


Figure 191: Cable Ducting in Middle Pedestal Section

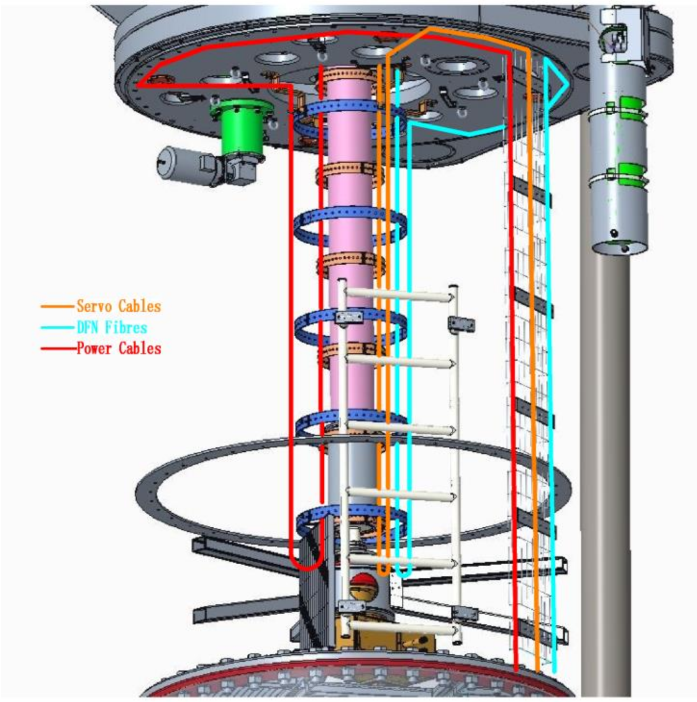


Figure 192: Cable Ducting in Upper Pedestal Section

Power cable line

The main power cable goes into the pedestal and then the pedestal power distribution box.

The PSC power supply cable and earth cable will go downward to the PSC EMI filters and then connect to the PSC power distribution box. Inside the PSC, the cables will distributed to EMISC, drive cabinet, fans, lights and socket.
The Indexer power supply cable and helium compressor power cable will go upward, through the middle and upper pedestal section, azimuth cable wrap and arrive at the turnhead.

Servo cable line
The servo cables firstly penetrate the servo cabinet through the EMI filters. Then they go through the metallic cable conduit and outlet the PSC at the ceiling. Along the cable tray, some of the servo cables will go upward to the azimuth I/O unit and azimuth stow motor. Some servo cables will go downwards to the lower pedestal section, where the cable penetrate the pedestal wall and connect with outdoor equipment. The rest of servo cables go through the azimuth cable wrap to the turnhead.

RF Fibre line
The fibre cables entry from the foundation into the pedestal, then go to the SaDT fibre patch panel in the middle pedestal section. From the patch panel, the fibres go down to the EMISC inside the PSC through the wave guide tube.
The DFN fibre cables to the indexer and turnhead leave the EMISC and go upward to the turnhead through the wave guide tube and the azimuth cable wrap.

PAF Fiber line
Yellow dot line
The PAF fiber cables are reserved. The main fibers cables from the foundation entry the pedestal and then go to the PAF patch panel in the middle pedestal section (reserved). Three PAF fibre cables leave the patch panel and go upward to the azimuth cable wrap. One PAF fibre cable goes down to the EMISC through the wave-guide tube.

3.2.11.3 Turnhead cable routing

The overview of cable routing inside the pedestal is shown as Figure 193 and Figure 194.

The servo cables to the azimuth actuator and elevation actuator will exit the turnhead from the rear.
The servo cables to the elevation I/O unit will outlet the turnhead at one of the turnhead vent.
The cable conduits are applied to protect the servo cables outside the turnhead

The helium pipes and hoses entry the turnhead at one of the vent and go into the elevation cable wrap.

The power and control cable of the helium compressor comes from the azimuth cable wrap and exit the turnhead at the vent and go into the helium compressor.

The power cable, servo cables and SaDT Fibres for the Indexer comes from the azimuth cable wrap and go into the elevation cable wrap.

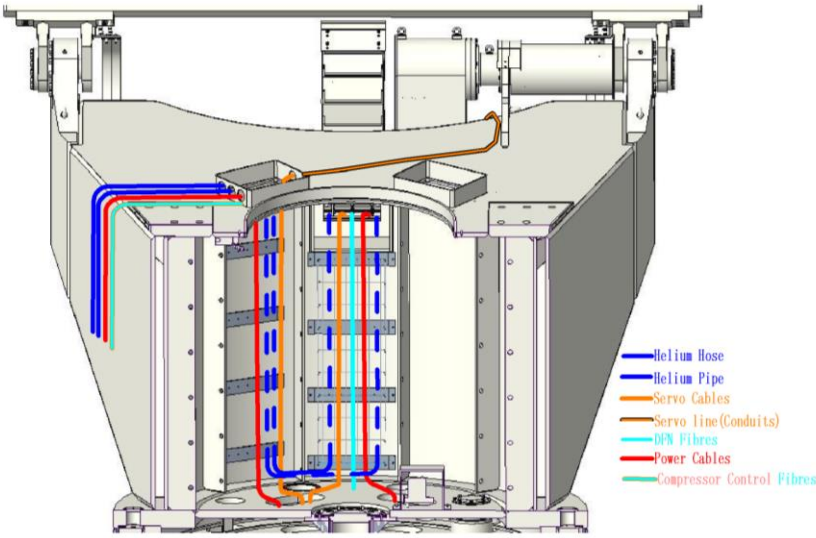


Figure 193: Cable Routing Inside the Turnhead

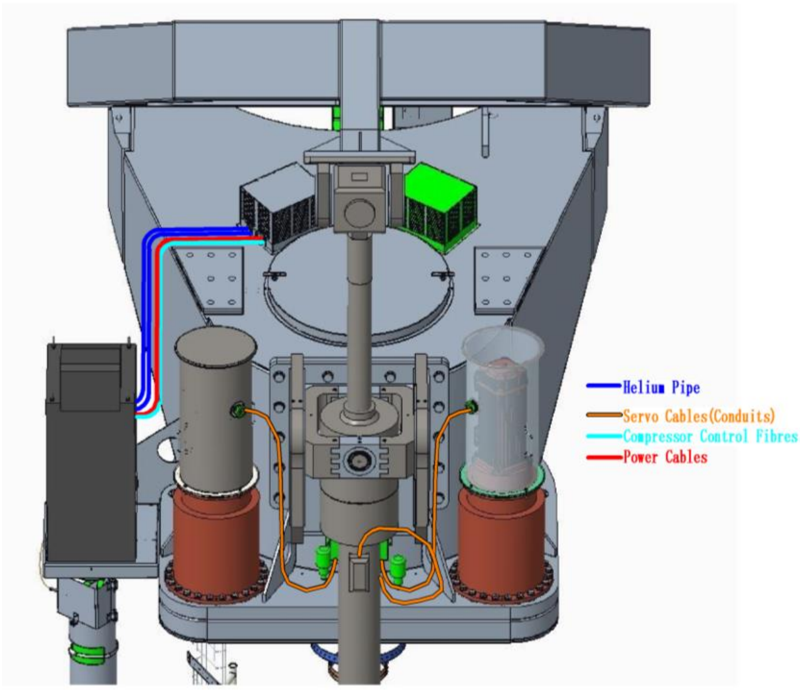


Figure 194: Cable Routing Outside the Turnhead

3.2.11.4 Elevation assembly cable routing

The elevation assembly cable tray is mounted on the backup structure, housing the power cable, servo cables and DFN fibres from elevation cable wrap to the feed indexer cable wrap, as shown in Figure 195.

The upper end of the cable tray is a large box with one side opened as shown in Figure 196. The box is mounted around the outlet of elevation cable wrap, providing space for the outlet cable and fibres. The cable tray stops at the bottom of the elevation assembly backup structure. The end of the cable tray is applied with various interfaces for the feed indexer cable wrap and other cable conduits

The cable tray is made of aluminium with certain thickness according to the lightning protection requirement.
The cable tray can be easily opened on one side, shown in Figure 197, allows easy installation and maintenance.

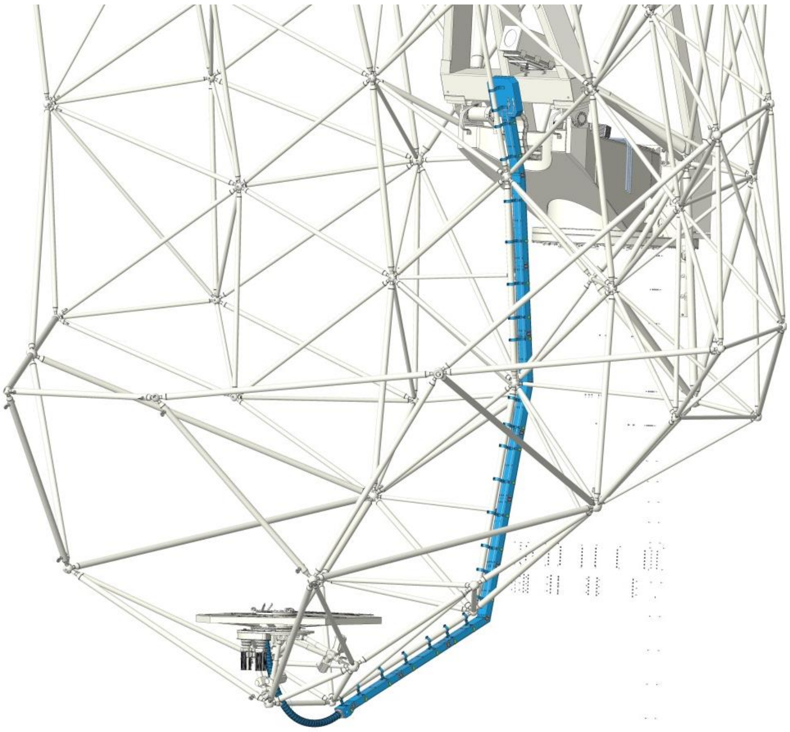


Figure 195: Elevation Assembly Cable Tray Overview

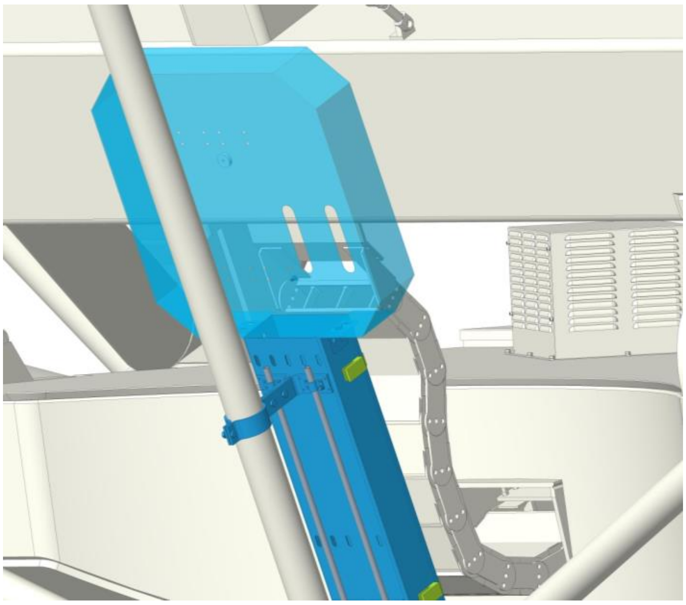


Figure 196 Upper End of the Elevation Assembly Cable Tray

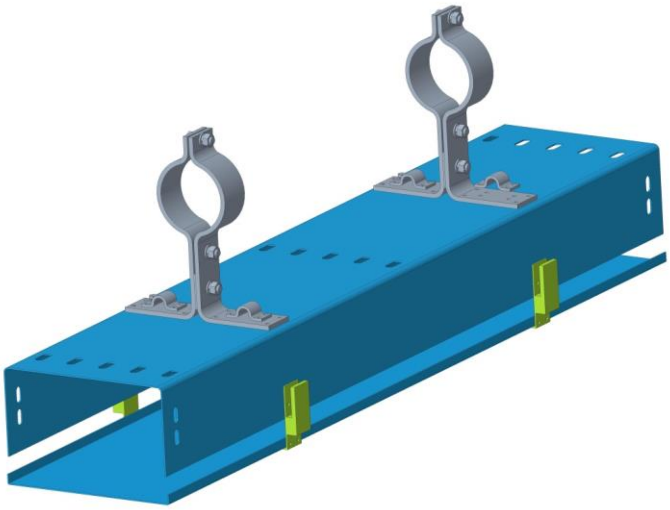


Figure 197: Cable tray with opened cover

The helium hoses and pipes will be mounted outside the cable tray. So the helium hoses exit the elevation cable wrap, bend inside the box of the cable tray and come out of the box, shown in Figure 198.

The routing of the rest cables and fibres are similar to the helium hoses and pipes except that they stay inside the cable tray.

At the Indexer cable wrap interface, the helium pipes entry the cable tray again and go into the feed indexer cable wrap, shown in Figure 199. As the indexer motors and I/O unit are not rotated with the indexer, the relevant servo cables exit the cable tray at the end and connect to the servo components.

The cable conduits are applied between the cable tray and the servo components to provide lightning protection and environmental protection.

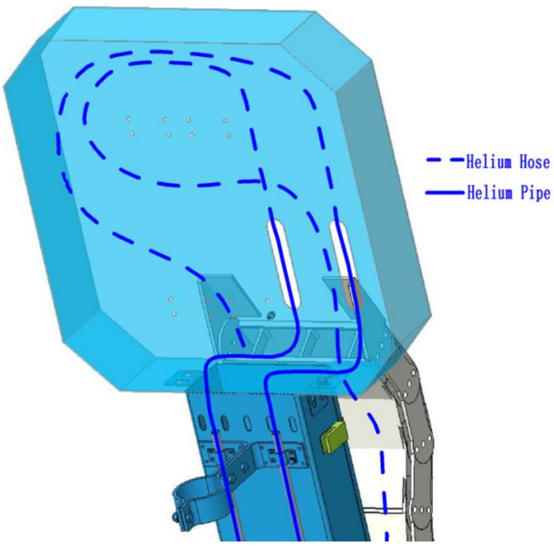


Figure 198: Cable routing from Elevation Cable Wrap to Cable Tray

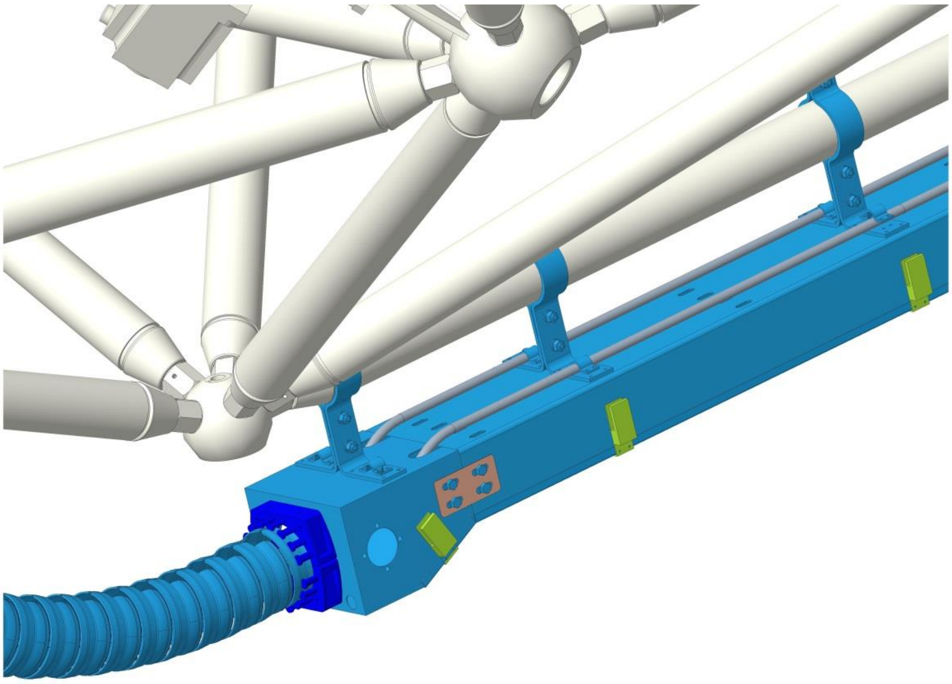


Figure 199: Cable Routing from Cable Tray to Feed Indexer Cable Wrap

3.2.12 Helium System Mount

The helium system mount is steel structure to support the helium compressor and to house the helium replenish bottle, as shown in Figure 200. The structure is fixed onto the floor plate of turnhead, next to one azimuth actuator. The air outlet is facing the backward of the elevation assembly and the cables connections toward the elevation cable wrap. The bottle is housed under the compressor, where the valve can keep away from rain and sunshine by the cover.

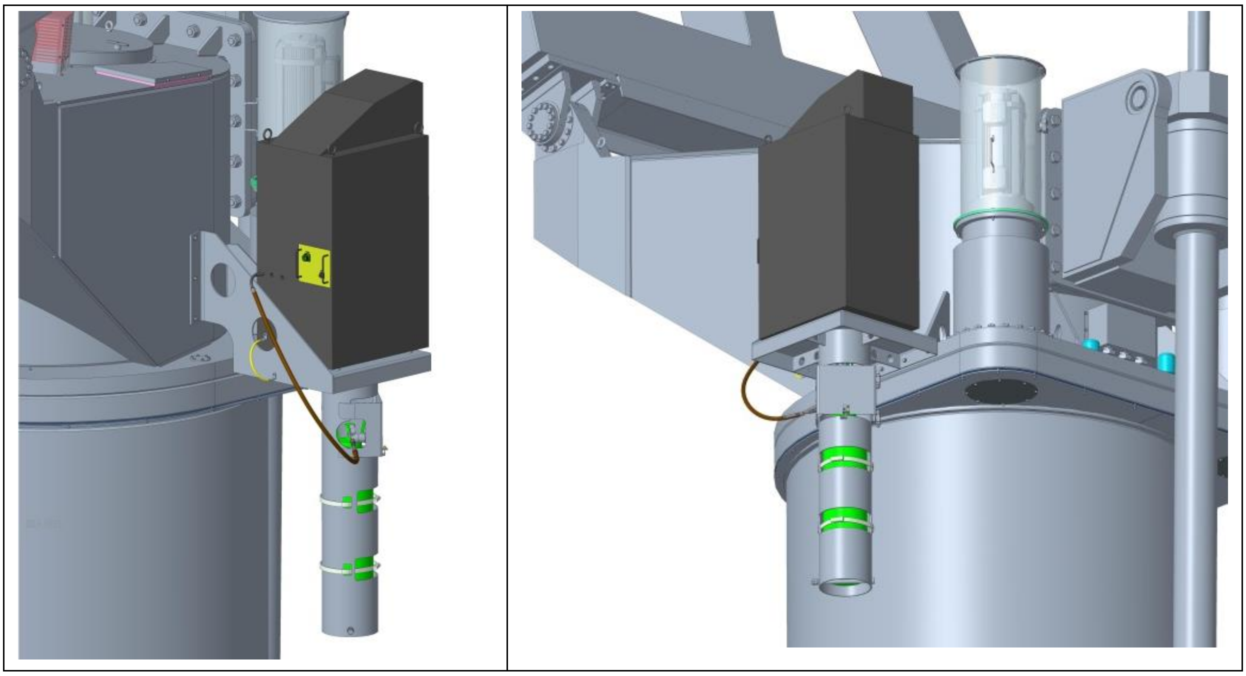


Figure 200: Model View of Helium Compressor Mount

The compressor can be moved to its mounting position using the crane from above. The maintenance work can be done on the cherry picker. The helium bottle can be replaced from the bottom using the cherry picker. A fixed pulley is applied above the bottle to easy the replacement of helium bottle. And the orientation of the valve is optimized for ergonomics as shown in Figure 201.
The clearance space of maintenance work has been checked.

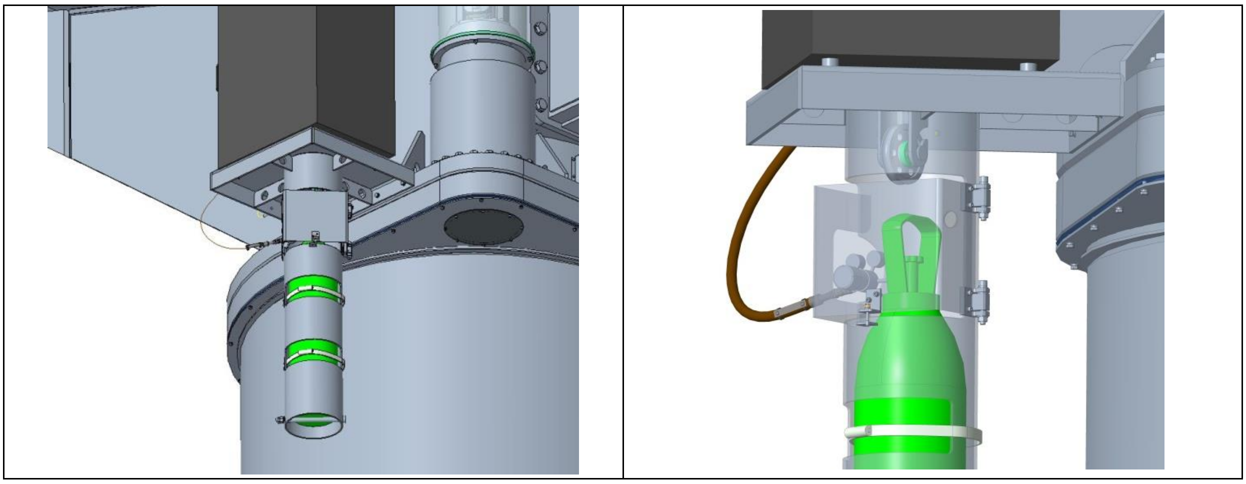


Figure 201: Design for Maintenance of Helium Replenish Bottle

3.2.13 Access Ladders

There is a general duty padlock for each pedestal door shown in Figure 202. Maintenance personnel can easily open the pedestal door from the outside. In case someone is locked inside the pedestal, the locking device can be easily disabled from the inside by loosen the handle as shown in Figure 203.

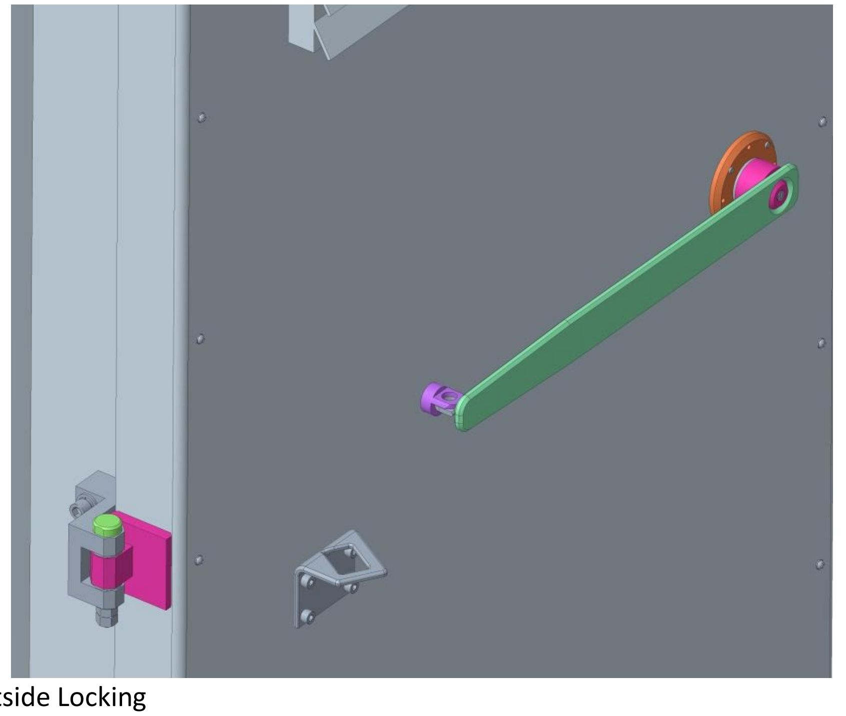


Figure 202: Outside Locking

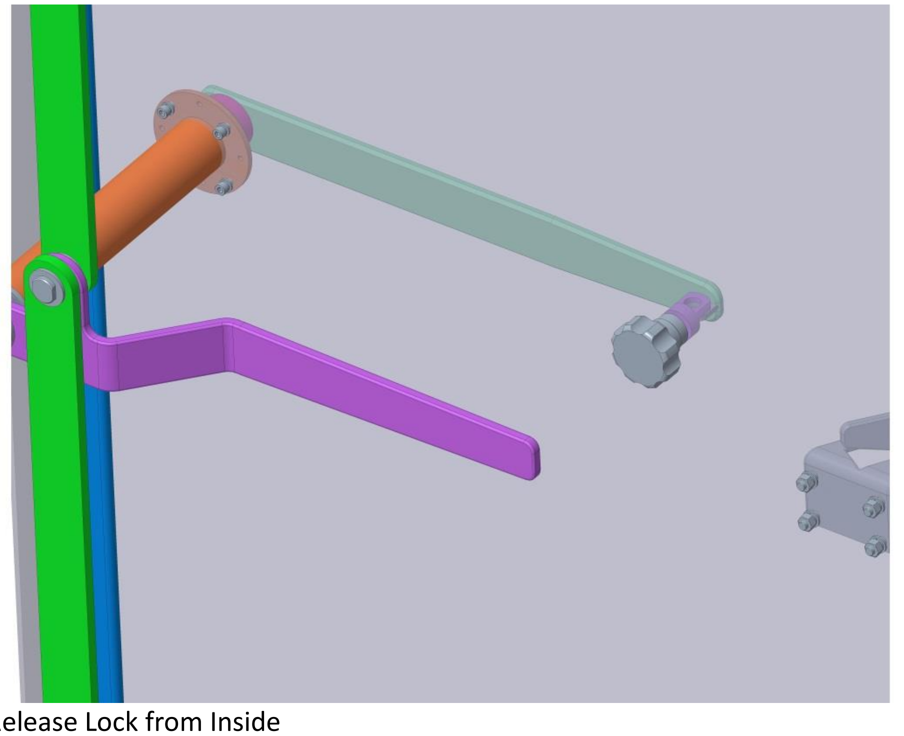


Figure 203: Release Lock from Inside

As shown in Figure 204, Once the pedestal door is opened at the maximum angle, the door will be latched automatically, which can protect personnel and devices from disoperation and the wind. The latch can be easily released to close the door.

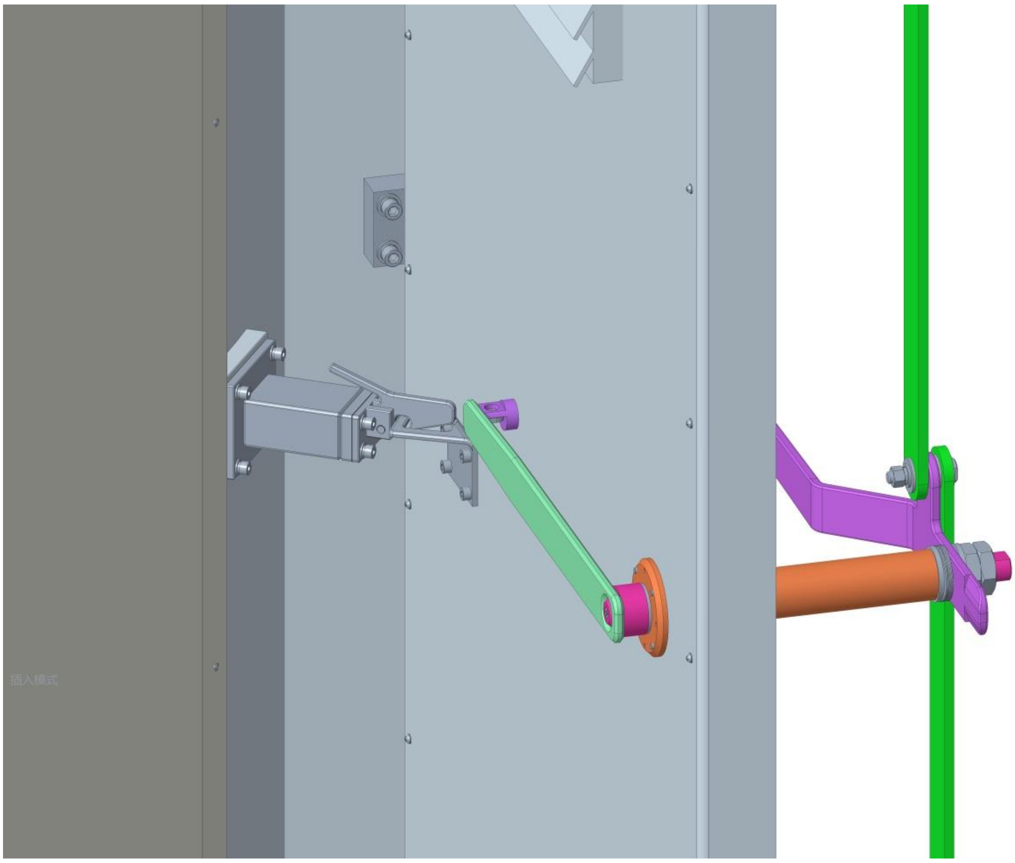


Figure 204: Automatically Latched Open

There are 4 ladders inside the pedestal. One small ladder is stowed on the main ladder in the lower section of pedestal, which provides open area for maintenance behind the main ladder. The main ladder allows personnel to access to the middle section of pedestal through the hatch. The open area of hatch is 530mm(width)*630mm(depth), as shown in Figure 205.

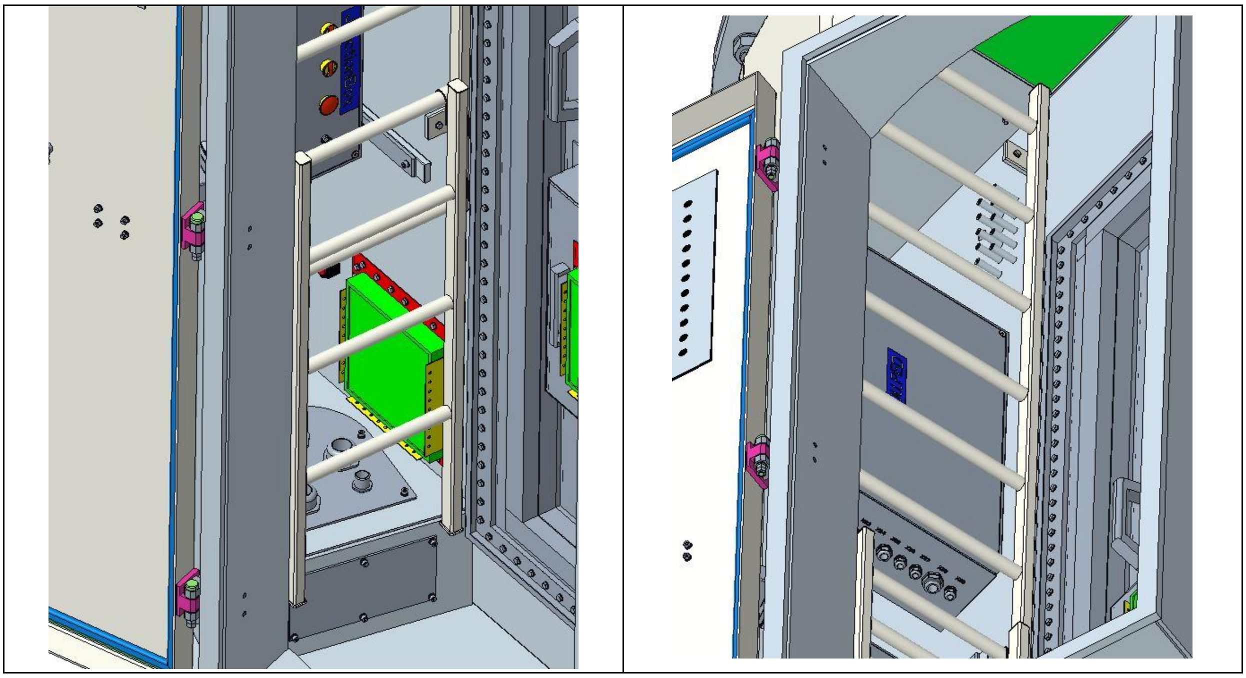


Figure 205 Ladders in the lower pedestal section

The ladders in the middle and upper sections of pedestal allow personnel to access to the upper section, as shown in Figure 206. The fixed platform between middle and upper sections of pedestal provides firm floor for maintenance work. The middle ring on the upper section pedestal wall is for temporary support, where a plate can be mounted to perform the maintenance on the ceiling of the upper section.

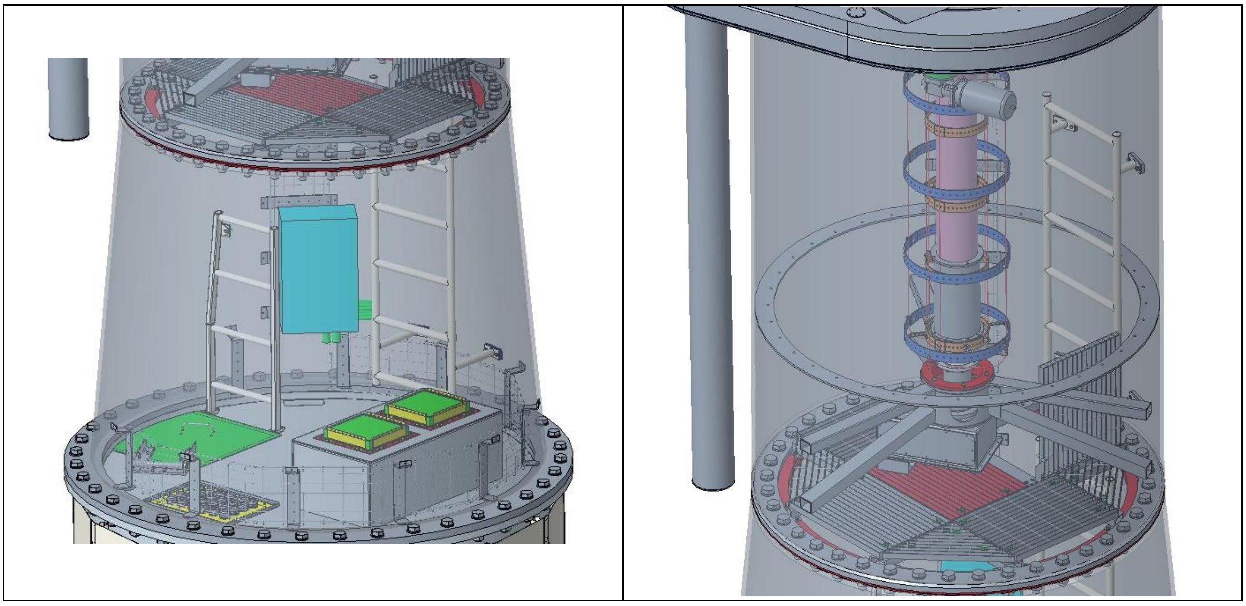


Figure 206 Ladders in the middle and upper sections of pedestal

The only access to the turnhead is the turnhead hatch, as shown in Figure 207. The hatch can be placed aside and locked onto the turnhead.

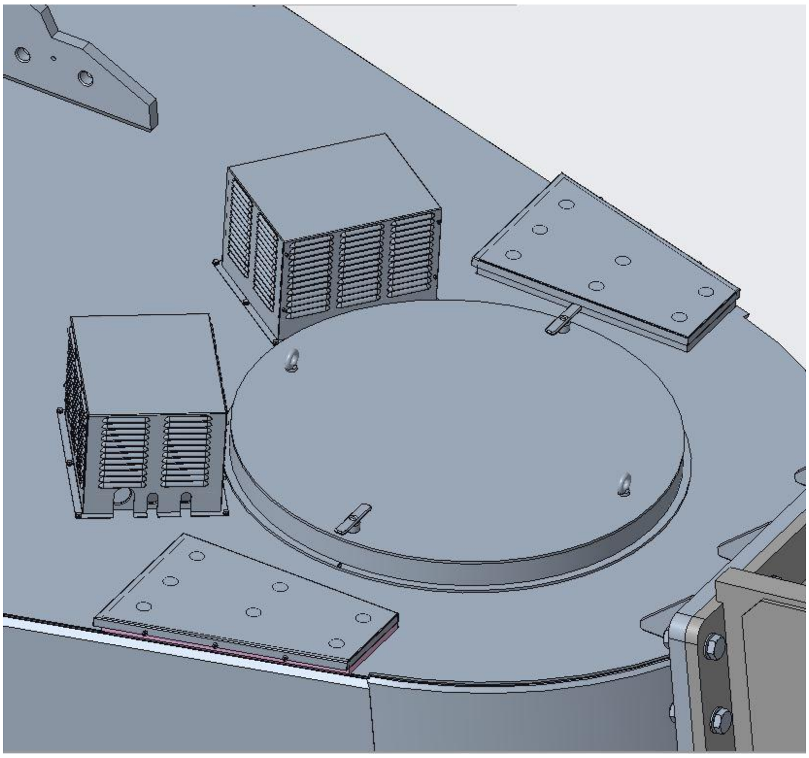


Figure 207 Turnhead hatch

3.2.14 Azimuth Bearing

The azimuth bearing provides azimuth axis rotation with low friction but high tilting stiffness to meet the allocated pointing error requirement. The azimuth drive is accomplished through a ring gear incorporated into the azimuth bearing.

The azimuth bearing adopts single row ball four point angular-contacts bearing with external gears similar to 011.45.1800, Rothe Eride Standard series KD600, as shown in as Figure 208 and Figure 209. Its normal rotation diameter is 1800mm and the parameters of gears are M=12 & Z=166.
The dimensions are same as

ROTHE ERDE Slewing Bearing 061.040.1800.13.19.1503,

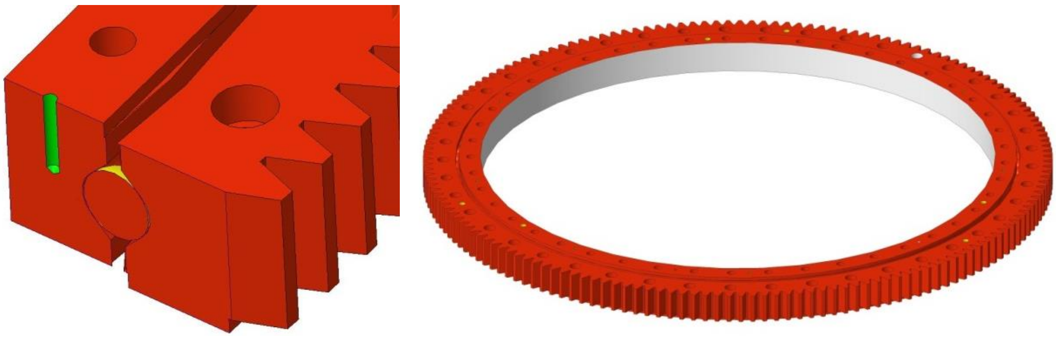


Figure 208: Azimuth Ball Bearing Overview

Standard series KD 600

Rothe Erde
Slewing Bearings

Bearings with external gear

Drawing No. Ball track dia. D_L [mm]	Weight [kg]	Outer diameter (O.D.) D_a [mm]	Inner diameter (I.D) D_i [mm]	Overall height H [mm]	External bolt circle dia. L_a [mm]	Internal bolt circle dia. L_i [mm]	Number of bolt holes per hole circle n	Bolt hole diameter B [mm]	Bolt size M [mm]	Number of grease nipples n_1	Diameter O [mm]	Diameter U [mm]	Ring height H_1 [mm]	Ring height H_2 [mm]	Distance at bottom Outer ring/inner ring H_u [mm]	Distance at top Outer ring/inner ring H_o [mm]	Gear P.C.D. d [mm]	Module m [mm]	Number of teeth z	Addendum modification sign per DIN 3960 October, 1976 $x \cdot m$ [mm]	Addendum reduction $k \cdot m$ [mm]	Tooth width b [mm]	Permissible tangential forces, normal [kN]	Permissible tangential forces, maximum [kN]	Curves
061.40.1400.000.19.1504 061.40.1400.001.29.1504	404	1593,6	1266	94	1482	1318	36	26	24	6	1401	1398	85	81	13	9	1560	12	130	+6,0	−1,2	85	64,05 93,6	128,1 187,2	15
061.40.1600.008.19.1503 061.40.1600.009.29.1503	479	1803,2	1466	94	1682	1518	40	26	24	8	1601	1598	85	81	13	9	1764	14	126	+7,0	−1,4	85	74,7 109,2	149,4 218,4	16
061.40.1800.013.19.1503 061.40.1800.014.29.1503	531	1999,2	1666	94	1882	1718	44	26	24	11	1801	1798	85	81	13	9	1960	14	140	+7,0	−1,4	85	74,7 109,2	149,4 218,4	17

Figure 209: Azimuth Ball Bearing Specification

For the static limiting load check, the wind load of 44m/s wind speed is considered. The axial load and moment load points on the azimuth bearing are shown as red points in Figure 210, It is shown that all the load points are below the curve No.17, indicating that the static load capacity of the bearing meets the requirement.

The service life calculation is based on the duty cycle and environmental condition, as shown in Figure 211. The wind load at the 13.5m/s wind speed is taken into the calculation as the operation time of the worse wind load is negligible. The calculated duty cycle is about 1039847 resolutions. Compared with the duty cycle per year, the expected service life is more than four times of the required 50 years.

The azimuth bearing is protected by the outside bearing cover against the dust and rain. There are twin auto air-operated greasers are equipped, of which the maintenance interval is estimated to be one year.

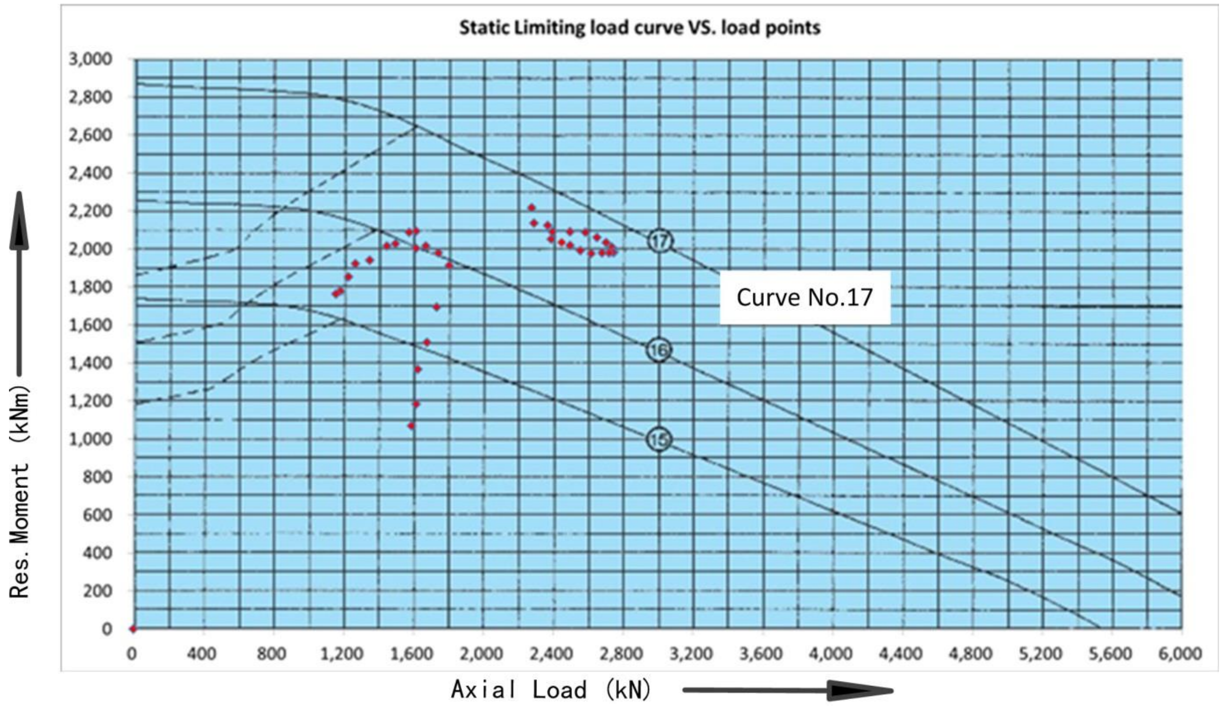


Figure 210: Azimuth Ball Bearing Static Limiting Load Curves

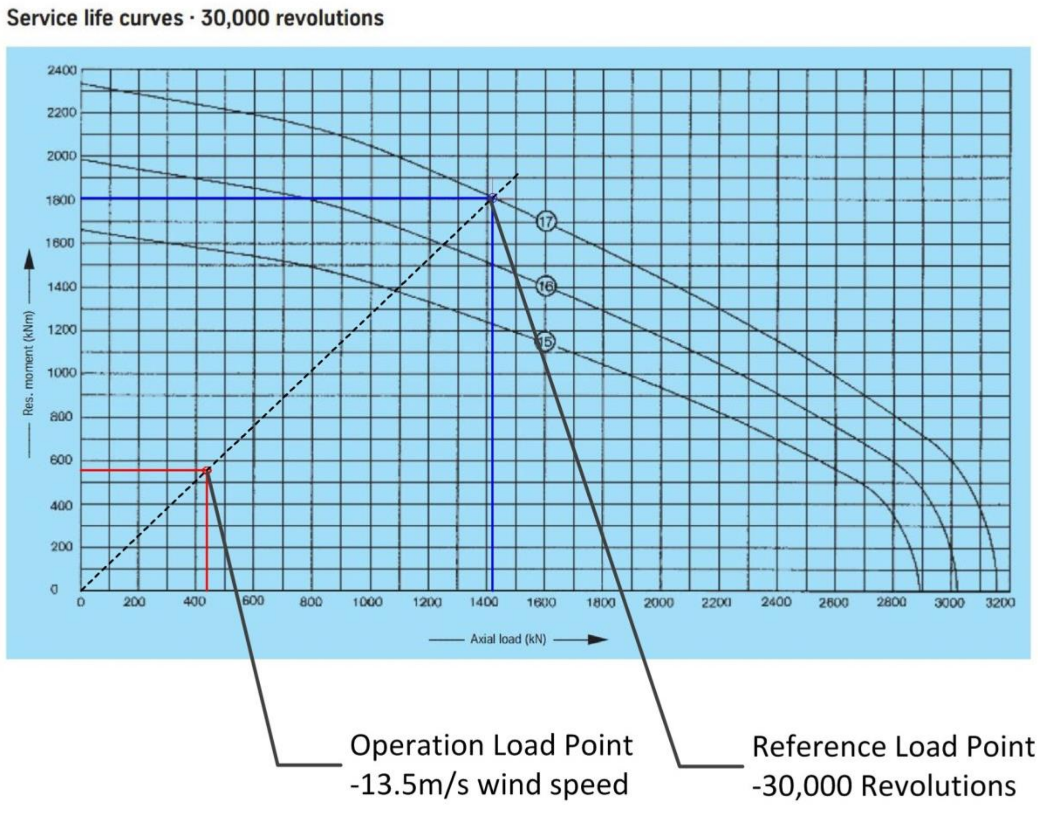


Figure 211: Operation Load Service Life

During the operation, the inside pedestal temperature may not be equal to outside. Considering the heat load inside the pedestal, the temperature may be higher than ambient temperature. Therefore the temperature of inner bearing ring is higher than outer ring, leading to the reduced backlash. Thus the bearing with backlash is selected for azimuth bearing. The required backlash is based on the temperature difference of 2 °C when the deformation difference between inner and outer rings can be 0.0432mm. Thus the backlash of azimuth bearing is required as 0.03mm-0.05mm.

3.2.15 Elevation Bearing

The elevation shaft bearings adopt dual cylindrical spherical roller bearing, which are good for reducing manufacturing accuracy and ensure elevation shaft self-centring during operation. The elevation bearings are shown in Figure 212.

The type of elevation bearings is standard COTS bearing, 22318CC-W33-GB288, of which the dimensions are D190 mm*D90 mm*64 mm.

The elevation bearing is housed in the elevation axis bracket on turn head, with protection seal on both sides. Each bearing is equipped with nipple for grease lubrication.

After inserted in to the bearing, each elevation pin is fixed to the bracket on elevation assembly interface frame. As the elevation pin has one side against the bearing, the total structure can prevent axial movement.

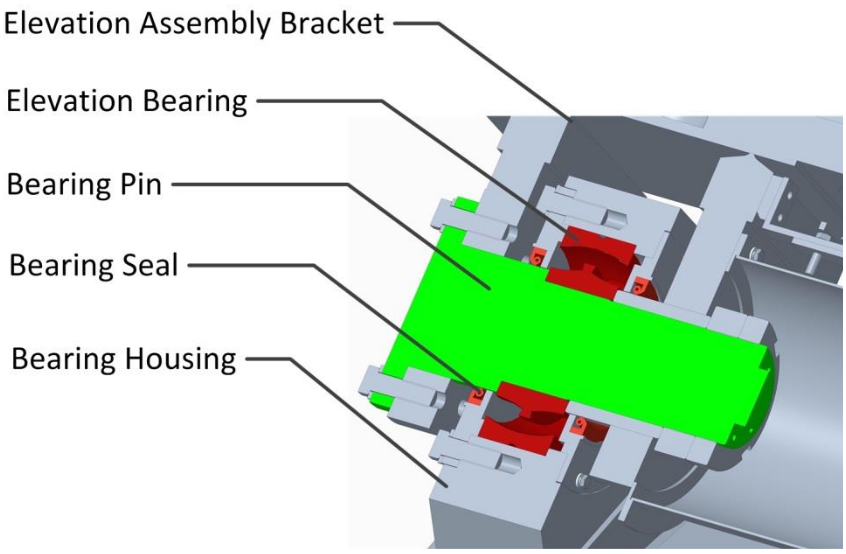


Figure 212: Elevation Bearing and Bracket

3.2.16 Azimuth Stow Lock

The azimuth stow lock consists of one stow actuator and four locking holes, as shown in Figure 213. The locking actuator is mounted under the ceiling of the pedestal upper section. There are four locking holes reserved, evenly distributed on the turnhead floor, of which one offset from true north is 45°. When stow is required, the turnhead can be driven to the nearest stow position and then be locked. The minimum azimuth slew range of stow is from 0° to 45° when applying total four locking shaft sleeves. This will be determined by the UPS battery configuration.

The azimuth actuator consists of motor, worm gear rod, locking pin and locking limit switches, as shown in Figure 214. The motor is a general three-phase asynchronous motor. The worm gear rod is selected from the COTS. The locking pin is made of high strength stainless steel to avoid slide friction due to the corrosion.

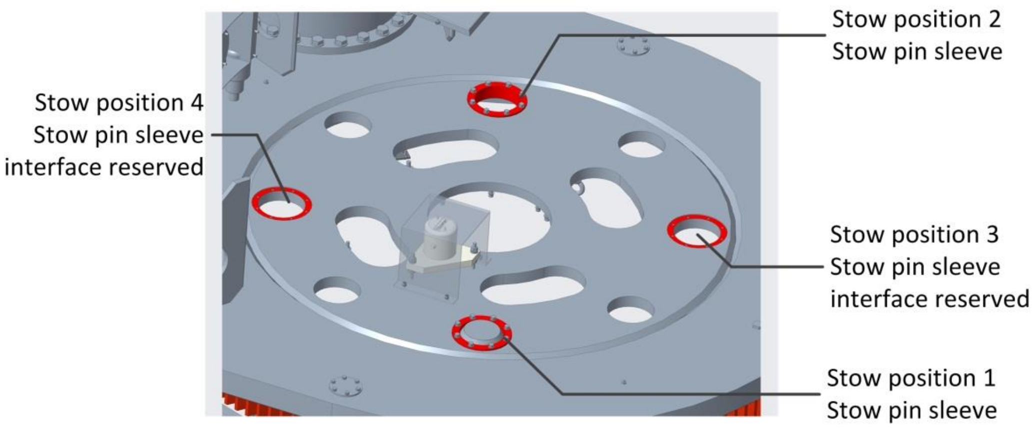


Figure 213: Distribution of Azimuth Stow Holes

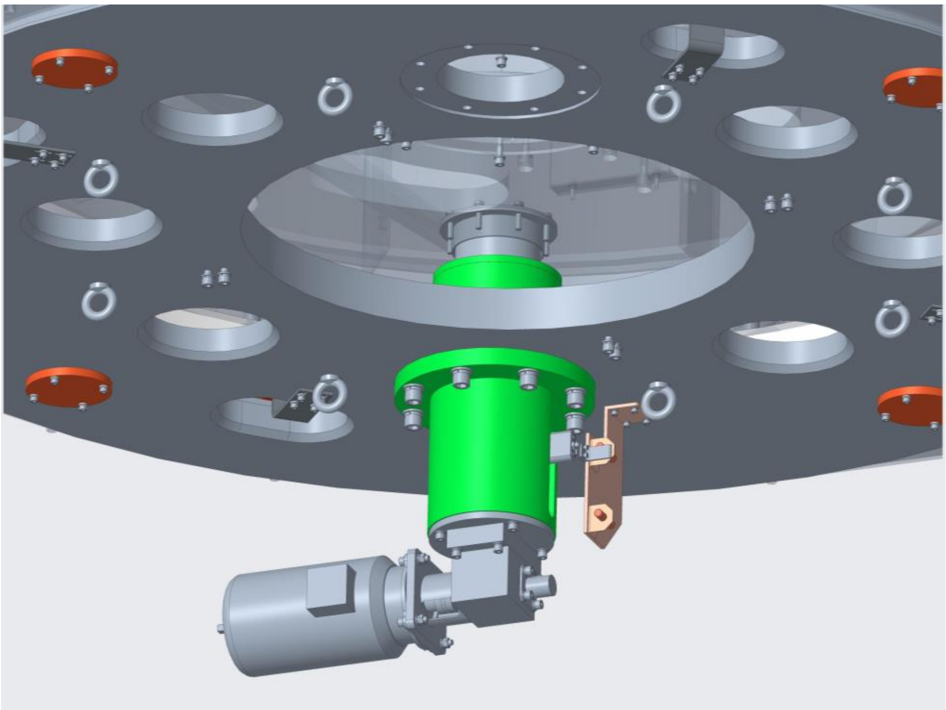


Figure 214: Azimuth Stow Motor and Locking Assembly

3.2.17 Brakes

The brakes for the main axes, azimuth, elevation and feed indexer, are part of the safety measures to provide a safe system to the operators and maintenance staff. They are separately controlled by the safety system and can only be opened when the safety systems derives a safe state of the telescope to be operated by reading all its sensors.

The brakes are an integral part of the motors (holding brakes per definition) and spring-closing. During loss of power, they will bring the telescope into a safe state. The brake torque shall be sufficient to hold the maximum motor torque and hold the maximum survival wind loads in the elevation stow position. They will stop all motion of the complete systems in a defined time, also considering reaction time and closing time.

3.2.18 Accessories

The pedestal assembly will be delivered with necessary accessories including:

- lighting (compliant with local and national regulations, e.g. issue of SANS 10114-1 in South Africa)

3.2.19 Control System NEW

3.2.19.1 Context

The general architecture of the control system is shown in Table 33
The context of the dish control system for the SKA telescope is shown in Figure 215 together with main other subsystems related to the telescope control system operation.

Table 33: Dish Control System main sub-systems

- **+D, drive cabinet**
    - **main power infeed and servo power distribution (incl. protections)**
    - **electronics power conversion and distribution (24VDC)**
    - **dish control system (ACU), incl. small 5min ups for controller only**
        - **remote interface (to LMC)**
        - **time interface (PTP / IEEE 1588)**
    - **dish safety system controller (LIS)**
    - **dish servo system amplifiers (VFDs)**
    - **auxiliary I/O System**
    - **EMI filters (red dots)**
- **azimuth axes**
    - **servo motors**
    - **I/O unit incl. position encoder and limit switches**
    - **stow pin motor and pin position feedback switches**
    - **axis tilt meter**
    - **EMI filters (red dots)**
- **elevation**
    - **servo motor**
    - **I/O unit incl. position encoder and limit switches**
    - **EMI filters (red dots)**
- **feed indexer**
    - **servo motors**
    - **I/O unit incl. position encoder and limit switches**
    - **EMI filters (red dots)**
- **ambient temperature measuring system based on three sensors**
- **warning light and horn**

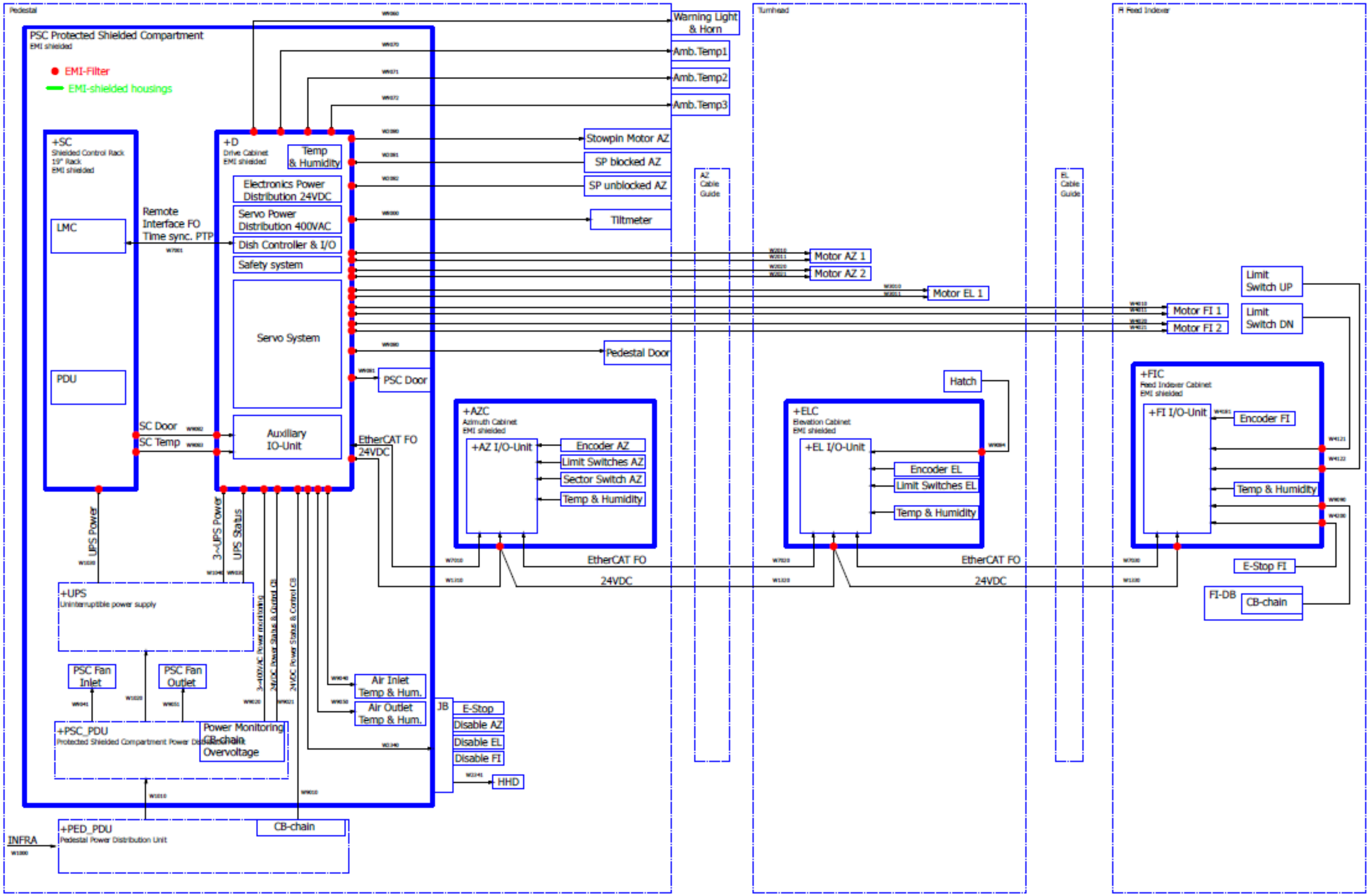


Figure 215: Control System Context

3.2.19.1 Block Diagram

Figure 216 shows a block diagram for the dish control system. The current control and servo systems installed by MTM on different telescopes are based on the experience over many years and different projects. Their reliability is based on major design aspects:

- high level of automation
- high reliability of equipment
- high availability applying built-in redundancy and low mean time to repair
- easy integration into existing M&C environment
- built-in test function and far-reaching diagnosis with remote access

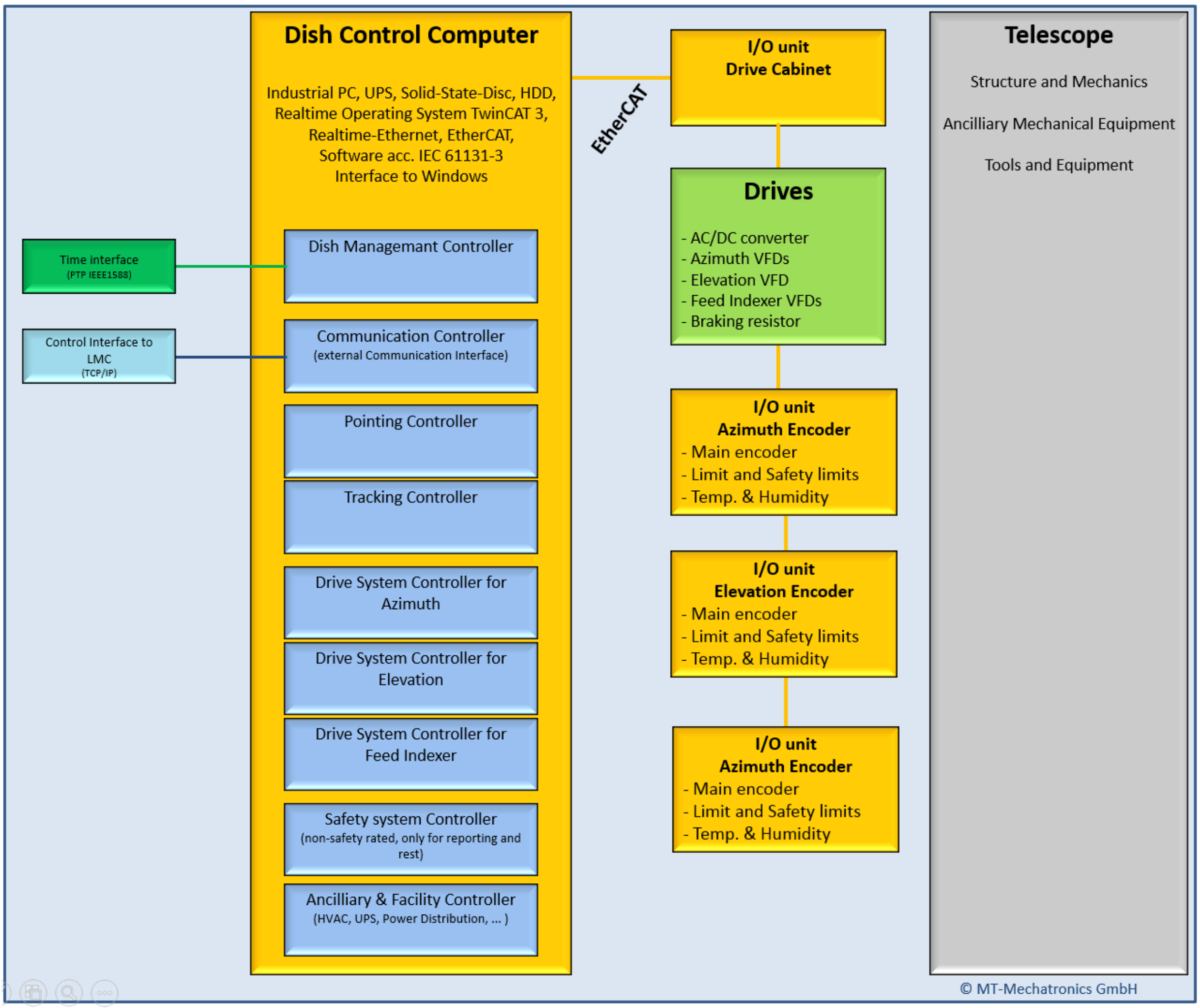


Figure 216: Block Diagram of the Dish Motion Control System Based on MTM Toolbox

The control solution is based on:

- control system with extensive tracking features
- stringent EMC design guidelines up to 100 GHz
- drive technology with state-of-the-art electronically pre-loaded servo motors and anti-backlash control

- high-resolution axis encoders
- real-time Ethernet field-bus system with flexible I/O system for minimum amount of cabling especially via cable wraps
- control technology based on high-quality commercial of-the-shelf components from automation industry in accordance with EMC and lightning protection criteria
- flexible TCP/IP Ethernet based client/server M&C concept with comprehensive visualization and interface for fully automated remote control compatible to existing interfaces
- proven software modules in accordance with EN 61131-3
- high real-time calculation power for complex numerical calculations.
- flexible design concept with redundancy and extensive diagnosis tools including remote online access
- design focused on reliability, availability and maintainability with low mean time to repair

3.2.19.2 Control Strategy

Apart from firmware of complex devices like the drive system, all essential telescope control software is implemented on the motion control computer.
The motion control software deployed on the DMCC is coded from MTM software engineers and responsible for the performance related tasks. Windows© and the real-time operating system TwinCAT (Beckhoff) reside in parallel to each other on the IPC hardware. Powerful communication lines between both operating systems exist. The following diagram shows this concept used in many automation applications:

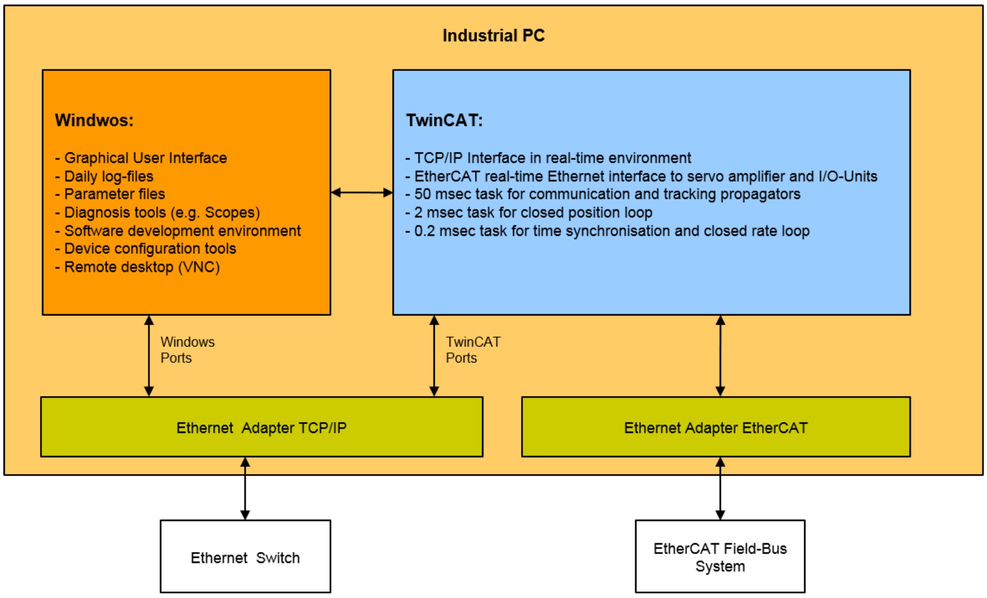


Figure 217: Software, Real Time and Normal Operating System

The main features of this concept are:

- all software tools are available under Windows©
- a GUI is implemented within Windows© and available via a portable unit
- advantage can be taken from the Windows© connectivity
- software within the real-time operating system TwinCAT is written according to guidelines for structured text, IEC 61131-3

- graduated task cycles are implemented, 0.5ms, 2ms and 50ms
- interrupt latency < 15 µs
- scalable calculation power between Windows© and TwinCAT

Especially diagnoses and error reporting are supported by this concept. Scope tools for analysis and debugging tools are installed under Windows©. Daily log-files can be generated in the Windows© part, too (optional). A GUI of the telescope control system uses a client / server concept and can be installed on any Windows© PC. Remote desktop software could also be used for operation on a remote PC as well.

3.2.19.3 Safety System and Interlocks

Beckhoff TwinSAFE is the basis which is used to compose the safety system. It provides the functionality to provide distributed safety chains with the advantage of reduction for cabling effort. The complete system is suitable for applications up to SIL 3 according to IEC 61508 and DIN EN ISO 13849 PLe.

Figure 218: Beckhoff Safety Terminals

The safety system for the telescope guarantees the safety of the telescope independently from the control system. Emergency stop push buttons are distributed throughout the telescope installation and access supervision is implemented by gate, hatch and door interlocks. Each push button and each interlock is monitored in the safety system to provide one or several logical interlock chains, improving the capabilities of the safety system to facilitate servicing, maintenance and testing. Main status information, together with the status of each individual interlock, is provided to the control system for user announcement. The concept can easily be extended when future needs require an update of functionality in logic and/or hardware.

The basis of the logics are four interlock chains:

- one overall interlock chain to gather all push buttons, hatches, doors and gates
- two main axis interlock chains, one for each main axis Azimuth and Elevation
- one interlock chain for the Feed Indexer

The first, overall interlock chain also acts on the two main axis and Feed Indexer chain to request stopping behavior.

The following safety interlocks are provided:

- overall interlock chain
  - E-Stop pedestal
  - E-Stop HHD
- azimuth chain
  - final limit +270°
  - final Limit -270°
  - locking pin
  - motion safety lock-out
- elevation chain
  - final limit +13°
  - final limit +92°
  - motion safety lock-out
- feed indexer chain
  - final limit -105°
  - final Limit +105°
  - motion safety lock-out

3.2.19.4 Cable List

The cables shown in Figure 215 are listed together with signal information in Table 34 as basis for the definition of the required filter (red dots) at the cable penetration.

Table 34: Servo System Cable List

Cable wrap application

n.a. = not applicable

! All cables shielded best as possible !

Item No.	Device	Cable number	Signal Type	Voltage	Current	Core number [mm^2]	Outer diamenter [mm]	Cable Type	Manufacturer/Supplier	Cable Length [m]	Remark
1	Warning Light & Horn	W9060	Signal	24VDC	<0,5A	4G1,0	7,4	Lapp Ölflex Robust 215C	Lapp	15	
2	Amb.Temp1	W9070	PT100	< 5VDC	<10mA	3x 0,5	6,2	Lapp Ölflex Robust 215C	Lapp	15	
3	Amb.Temp2	W9071	PT100	< 5VDC	<10mA	3x 0,5	6,2	Lapp Ölflex Robust 215C	Lapp	15	
4	Amb.Temp3	W9072	PT100	< 5VDC	<10mA	3x 0,5	6,2	Lapp Ölflex Robust 215C	Lapp	15	
5	Stowpin Motor AZ	W2080	Power	3~400VAC, 50Hz	<2A	4G1,5	8,4	Lapp Ölflex Classic 135CH	Lapp	25	
6	SP blocked AZ mit M12 Buchse	W2081	Signal bn(1), wh(2), bu(3), bk(4)	24VDC	<200mA	4x0,34	8,3	AB-C4-25,0PUR-M12FS-SH	Lapp	25	M12 connector female at one end
7	SP unblocked AZ mit M12 Buchse	W2082	Signal bn(1), wh(2), bu(3), bk(4)	24VDC	<200mA	4x0,34	8,3	AB-C4-25,0PUR-M12FS-SH	Lapp	25	M12 connector female at one end
8	Tiltmeter	W8000	Signal analog	±12VDC, ±0…8VDC analog	<20mA	10x0,34	9	Cable on device 30m	n.a.	30	
9	Motor AZ1	W2010	Power /Brake	3~ 0-350VAC, 0-800Hz / Brake 24VDC	13,5A /1,5A	(4x2,5 + (2x0,5))	14,2	EYP0012Y0300A00A00	Lenze	30	
10	Motor AZ1	W2011	Motor Encoder	24VDC	<0,5A	4(2×0.14) + (2×1.0)	10,8	EYF0019A0300A00S03	Lenze	30	SubD15 Male at one end
11	Motor AZ2	W2020	Power /Brake	3~ 0-350VAC, 0-800Hz / Brake 24VDC	13,5A /1,5A	(4x2,5 + (2x0,5))	14,2	EYP0012Y0300A00A00	Lenze	30	
12	Motor AZ2	W2021	Motor Encoder	24VDC	<0,5A	4(2×0.14) + (2×1.0)	10,8	EYF0019A0300A00S03	Lenze	30	SubD15 Male at one end
13	Motor EL1	W3010	Power /Brake	3~ 0-350VAC, 0-800Hz / Brake 24VDC	18A/TBD	(4x4 + (2x0,5))	15,8	EYP0053Y0300A00A00	Lenze	30	
14	Motor EL1	W3011	Motor Encoder	24VDC	<0,5A	4(2×0.14) + (2×1.0)	10,8	EYF0019A0300A00S03	Lenze	30	SubD15 Male at one end
15	Motor FI1	W4010	Power /Brake	3~ 0-350VAC, 0-800Hz / Brake 24VDC	3,3A /0,75A	(4x1,5 + (2x0,5))	11,3	EYP0011Y0400A00A00	Lenze	40	
16	Motor FI1	W4011	Motor Encoder	24VDC	<0,5A	4(2×0.14) + (2×1.0)	10,8	EYF0019A0400A00S03	Lenze	40	SubD15 Male at one end
17	Motor FI2	W4020	Power /Brake	3~ 0-350VAC, 0-800Hz / Brake 24VDC	3,3A /0,75A	(4x1 + (2x0,5))	11,3	EYP0011Y0400A00A00	Lenze	40	
18	Motor FI2	W4021	Motor Encoder	24VDC	<0,5A	4(2×0.14) + (2×1.0)	10,8	EYF0019A0400A00S03	Lenze	40	SubD15 Male at one end
19	Ethercat FO beidseitig SC	W7010	Fiber Multimode-Glasfaser 50/125 µm	n.a.	n.a.	2	12	Trunk TORSION 2G50/125 OM2	Lapp	20	
20	Ethercat FO beidseitig SC	W7020	Fiber Multimode-Glasfaser 50/125 µm (MM)	n.a.	n.a.	2	12	Trunk TORSION 2G50/125 OM2	Lapp	25	
21	Ethercat FO beidseitig SC	W7030	Fiber Multimode-Glasfaser 50/125 µm (MM)	n.a.	n.a.	2	12	Trunk TORSION 2G50/125 OM2	Lapp	20	
22	24VDC Control Power	W1310	Control Power	24VDC	<5A	2x1,5	8,3	Ölflex FD855CP	Lapp	20	
23	24VDC Control Power	W1320	Control Power	24VDC	<5A	2x1,5	8,3	Ölflex FD855CP	Lapp	25	
24	24VDC Control Power	W1330	Control Power	24VDC	<5A	2x1,5	8,3	Ölflex FD855CP	Lapp	20	
25	JB	W2340	Signal	24VDC	<10mA	41G0,75	20,6	Lapp Ölflex Classic 400CP	Lapp	25	
26	HHD	W2341	Signal	24VDC	<10mA	25x0,5	13,7	Lapp Ölflex Classic 135CH	Lapp	10	
27	Pedestal Door	W9080	Signal	24VDC	3mA	2x0,5	5,9	Lapp Ölflex Classic 135CH	Lapp	10	
28	PSC Door	W9081	Signal	24VDC	3mA	2x0,5	5,9	Lapp Ölflex Classic 135CH	Lapp	10	
29	Air Inlet Temp. & Humidity	W9040	Signal	0-10V analog	<10mA	4x0,5	6,6	Lapp Ölflex Classic 135CH	Lapp	10	
30	Air Outlet Temp. & Humidity	W9050	Signal	0-10V analog	<10mA	4x0,5	6,6	Lapp Ölflex Classic 135CH	Lapp	10	
31	PED DB (CB-chain)	W9010	Signal	24VDC	3mA	7x0,5	7,7	Lapp Ölflex Classic 135CH	Lapp	15	
32	PSC DB (CB-chain & CB control)	W9021	Signal	24VDC	3mA & < 50mA	7x0,5	7,7	Lapp Ölflex Classic 135CH	Lapp	10	
33	PSC DB (Power Monitoring))	W9020	Power	3~400VAC, 50Hz	<1A	12G0,75	11,1	Lapp Ölflex Classic 135CH	Lapp	10	
34	SC Door switch	W9082	Signal	24VDC	3mA	2x0,5	5,9	Lapp Ölflex Classic 135CH	Lapp	5	
35	SC Temp	W9083	PT100	< 5VDC	<10mA	3x 0,5	6,2	Lapp Ölflex Classic 135CH	Lapp	5	
36	Hatch switch	W9084	Signal	24VDC	3mA	2x0,5	5,9	Lapp Ölflex Classic 135CH	Lapp	5	
37	Limit Switch FI UP	W4122	Signal	24VDC	<10mA	5G1,0	8,3	Lapp Ölflex Classic 135CH	Lapp	10	
38	Limit Switch FI DN	W4121	Signal	24VDC	<10mA	5G1,0	8,3	Lapp Ölflex Classic 135CH	Lapp	10	
39	FI CB Chain	W9090	Signal	24VDC	3mA	2x0,5	6,7	Ölflex FD855CP	Lapp	10	
40	FI Estop	W4200	Signal	24VDC	<10mA	5G1,0	9,6	Ölflex FD855CP	Lapp	10	
41	UPS (Power)	W1040	Power	3~400VAC, 50Hz	32A	5G6	15,5	Lapp Ölflex Classic 135CH	Lapp	10	

3.2.19.5 Drive Cabinet

The drive cabinet will interface to, or contain all equipment related and responsible to move the telescope to point and track the astronomical sources of interest.

The following main parts are installed in the drive cabinet itself:

- main power infeed and servo power distribution (incl. protections)
- electronics power conversion and distribution (24VDC)
- main drive amplifiers (VFDs) for azimuth, elevation and feed indexer axes
- antenna control system
- antenna safety system
- auxiliary I/O system

The drive cabinet supplier is selected to be Frankonia Germany providing extensive support during design and manufacturing. The cabinet's size shown in Figure 220 is: width 600 mm, depth 500 mm, height 1800 mm. On the lower part of Figure 220 the cable penetrations are listed according cable list in [RD4] and the servo system diagram shown in Figure 215 and annexed as [RD2].

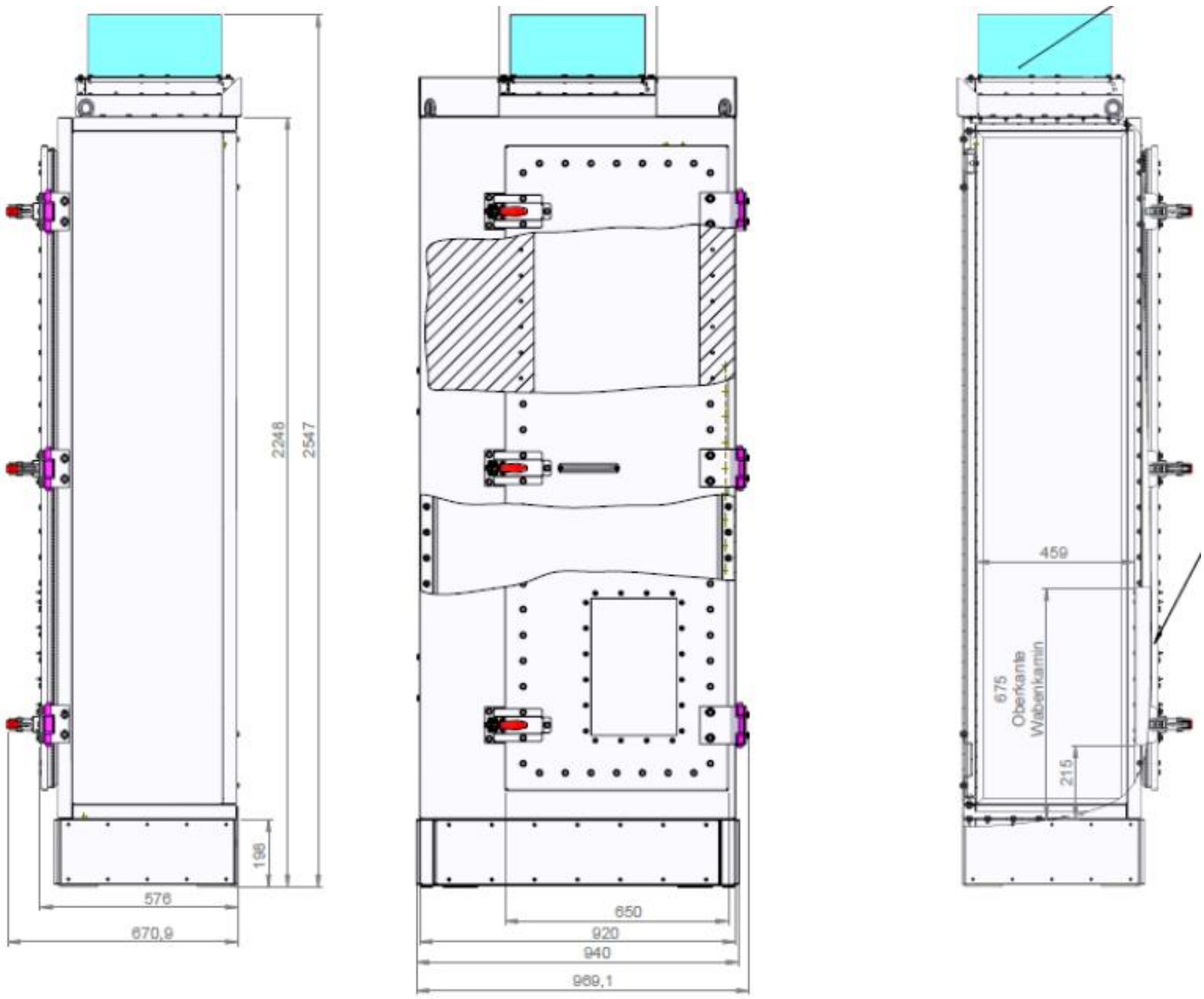


Figure 219: Drive Cabinet

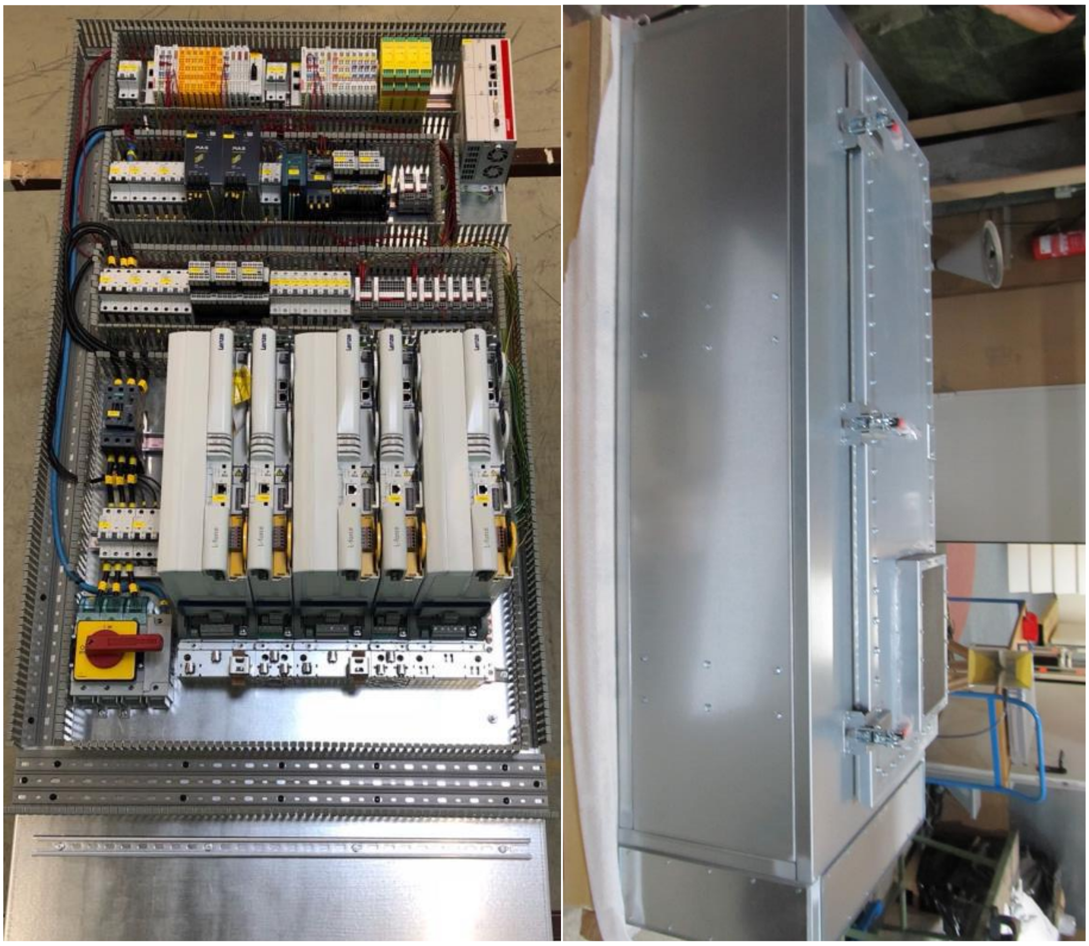


Figure 220: Drive Cabinet Details and Internal Layout

Cable penetrations are on the bottom for power infeed and larger size cables. On the top of the cabinet, there are penetrations for smaller size signal cables and especially all cables that will have to be routed to the turn head above the cabinet. In Figure 220 the penetrations are shown together with the cable identifier corresponding to the cable list and the servo layout diagram.
The cabinet contains no active temperature control, only a fan is installed in the top of the cabinet to push hot air out of the cabinet into the pedestal-shielded compartment when the temperature is above a threshold. The cool air will enter the cabinet through an equal-sized opening on the bottom of the cabinet door, both opening (air inlet and air outlet) are equipped with an EMI filter.

The following main equipment is selected to constitute the drive cabinet components:

- Frankonia for the cabinet and Rittal for minor equipment as light, fans, or grounding bus bar
- Beckhoff, as the basic automation platform for the control and safety system (MTM standard)
- Lenze, as the drive system supplier for rectifiers, VFDs, net filters, motors and cables (refer to [RD5] and [RD6])
- Puls, for the redundant 24VDC power supplies
- Weidmüller, for terminal blocks and wire management

The drive cabinet is placed inside the pedestal-shielded compartment shown in the figure below.

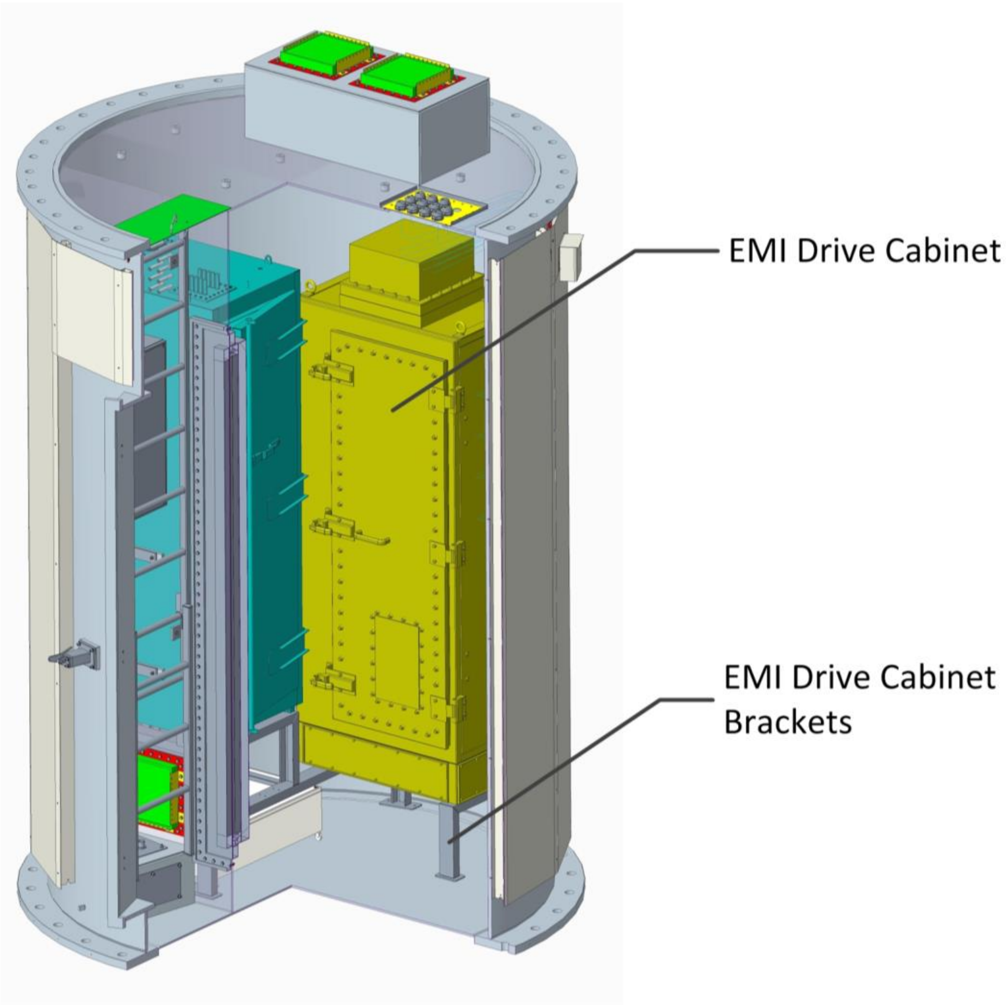


Figure 221 Drive Cabinet inside PSC

4 Performance Statement

4.1 States & Modes

The overall state diagram of the telescope is shown in Figure 222 and available via the Management Controller Status. It is derived according the combination of several individual states and modes to simplify the usage of the Dish Control System for routine operation.
For detailed information of individual states, more state diagrams are available in section ？？？

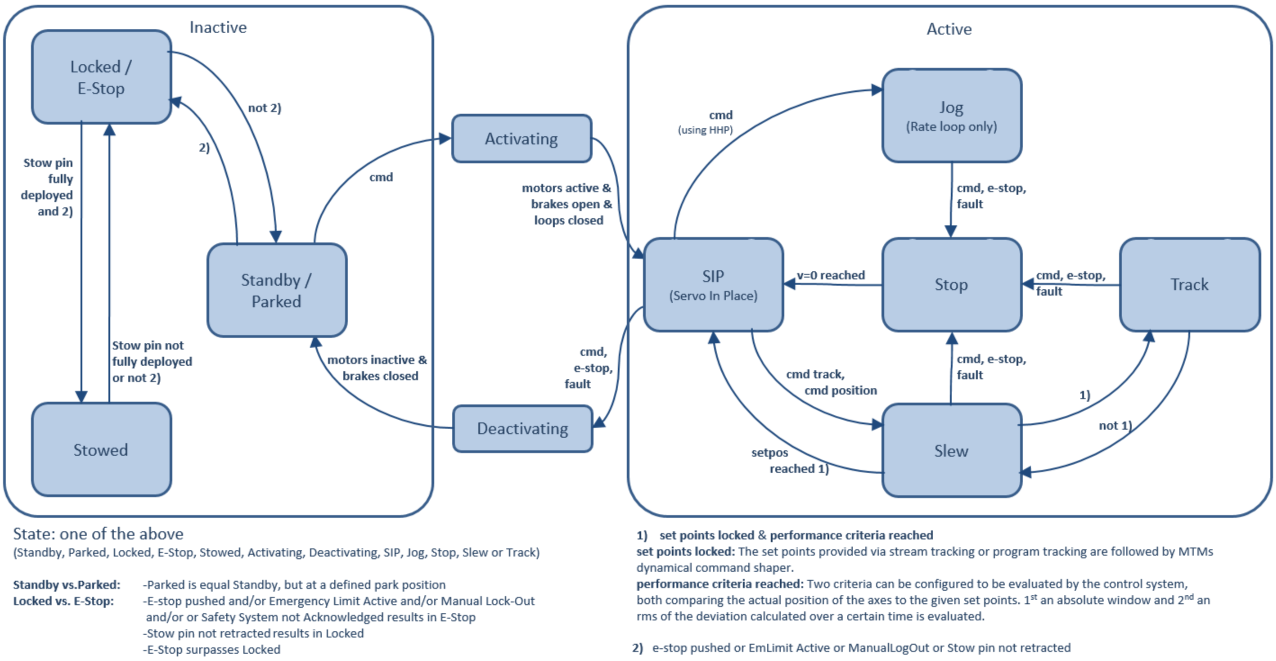


Figure 222 States and Modes for the General Telescope Status

The following table lists the dependency of the General Telescope Status from the individual axes states.

General State	Azimuth	Elevation	Feed Indexer
Locked	at least one of the three being locked, meaning manual intervention required before next tracking is possible		
Stowed	Stowed	Parked_01	any state
Parked	Parked_xx	Parked_yy	any state
	Parked_xx	Standby	
	Standby	Parked_yy	
Standby	Standby	Standby	any state
	any other active mode	Standby	
	Standby	any other active mode	
SIP	SIP	SIP	any state
Slew	SIP	Slew	any state
	Slew	SIP	
	Slew	Slew	
	Track	Slew	
	Slew	Track	
Track	Track	Track	FI parked @ Band nn
Stop	Stop	Stop	any state
	Stop	any other active mode	
	any other active mode	Stop	

Figure 223 Azimuth and Elevation to General Status transition table

<u>Technical Data:</u>

Physical and data link layer:	10 / 100 / 1000 BASE-T Ethernet	
Network and transport layer:	TCP/IP class B network	
Byte order:	Little Endian (Intel Format)	
IP Address ACU:	Defined by configuration file	
Server:	ACU	
Ports:	Command port:	Defined by configuration file
	Status message port:	Defined by configuration file

The TCP/IP connection is supervised by a watchdog in the network layer. The ACU generates a software interlock in remote control mode as well as in local control mode if the connection is lost.

In order to increase overall system performance a binary data representation is used. The standard data types are:

INT8	8 Bit signed
INT16	16 Bit signed
INT32	32 Bit signed
UINT8	8 Bit unsigned
UINT16	16 Bit unsigned
UINT32	32 Bit unsigned
WORD	16 Bit unsigned, used for in bit mode coded data
DWORD	32 Bit unsigned; used for in bit mode coded data
REAL32	32 Bit floating point
REAL64	64 Bit floating point
CHAR[]	ASCII character strings

A dedicated remote interface control document defines all relevant parameters for that communication. This document 301-000000-039 can be also found in the SKA Repository.

SKA Dish Structure Controller

Remote Interface Control Document

SKA Dish Structure Controller

Remote Interface Control Document

301-000000-039

Revision: 01
Revision Date: 20. June 2018

MT Mechatronics	Name	Date	Signature
Created by:	Steffen Seubert	Steffen Seubert (Jun 20, 2018)	
Reviewed by:	Ralf Moik	R. Moik	
Released by:	Lutz Stenvers	Lutz Stenvers Lutz Stenvers (Jun 21, 2018)	

Remote Interface Control Document
301-000000-039 Proprietary of MT Mechatronics GmbH Page 1 of 68

Figure 224: Signed Remote ICD for Dish Structure Controller to LMC

As the MTM standard control system software “MTM7” is used for the dish controller (see also Figure 216) the dish controller will not participate in the TANGO framework. The LMCs responsibility is to translate between the two systems. A mapping of states and modes on the LMC side from TANGO to MTM controller and vice-versa will be supported by MTM during the integration of both systems.

The general structure of the control system is given below. The Real Time Framework is responsible for all communications within the control system, provides several databases and the handling of the different time sources.

Each of the modules can be commanded from and provides individual status to different sources available. Individual modules are identified by their module id (red).

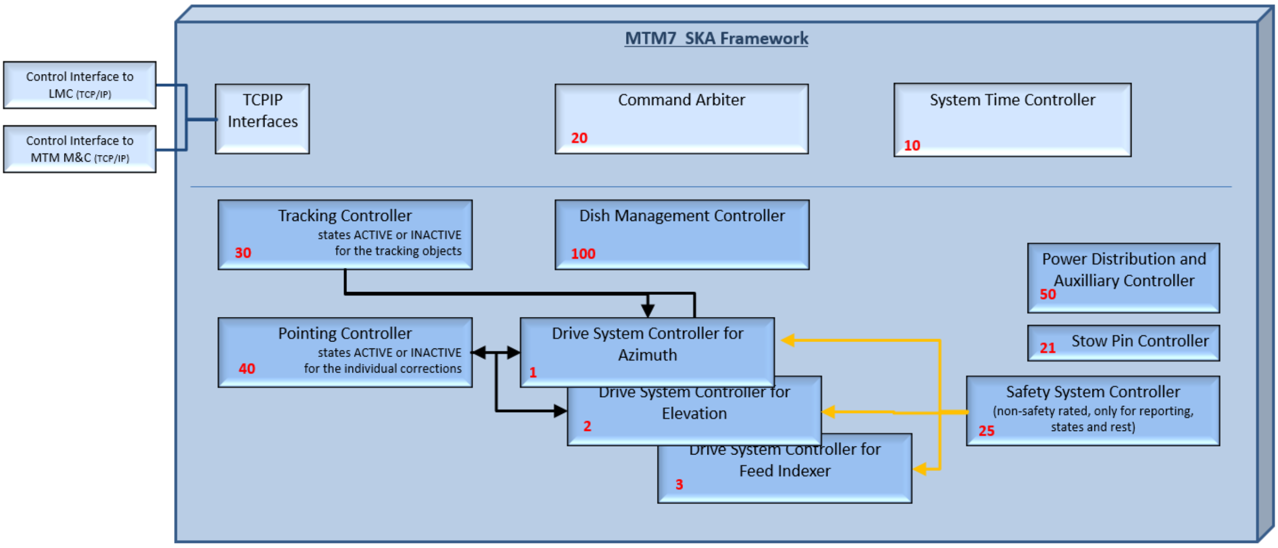


Figure 225 Software modules of the MTM7 SKA Dish Controller

- The Engineering user interface is located on the control computer and accessible via remote desktop sharing. This GUI enables the maintenance personnel to control an individual dish without any connection to the Local M&C or SaDT Network. It directly controls the DS controller.

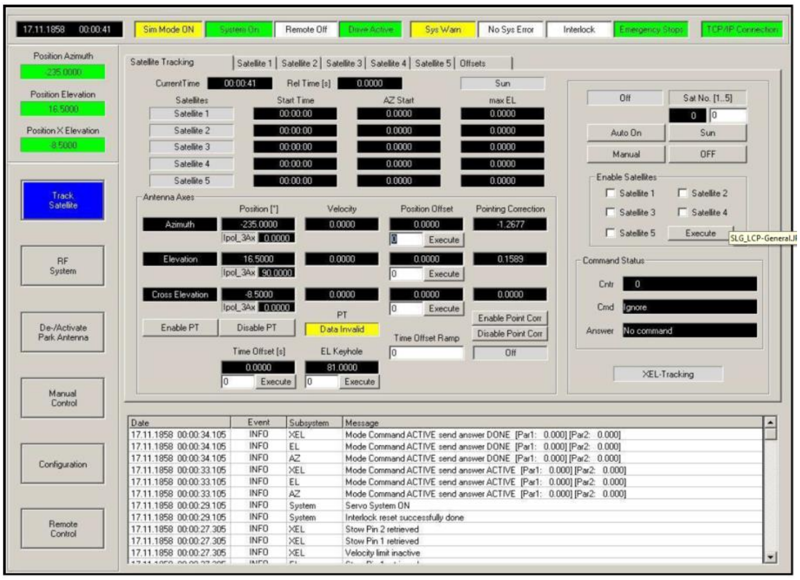


Figure 226: Maintenance GUI Example

- Handheld Device: For manual control and maintenance tasks a handheld device (HHD) can be connected. The HHD is equipped with an emergency stop and relevant push-buttons to move azimuth, elevation and feed indexer. When connected motion is only possible from the HHD.

Figure 227: Handheld Device

This device can be used on all dishes (not supplied with each dish) and should be part of a basic maintenance kit. As the engineering GUI, it also directly controls the DS controller.

- The system can be disabled for each axis individually to prevent motion, see Figure 228. Electromechanical safety brakes are used to prevent motion. Those brakes are controlled via the safety system and can only be opened by the control system when the telescope is in a safe condition and the disable switches on the lockout-tag-out box are released.

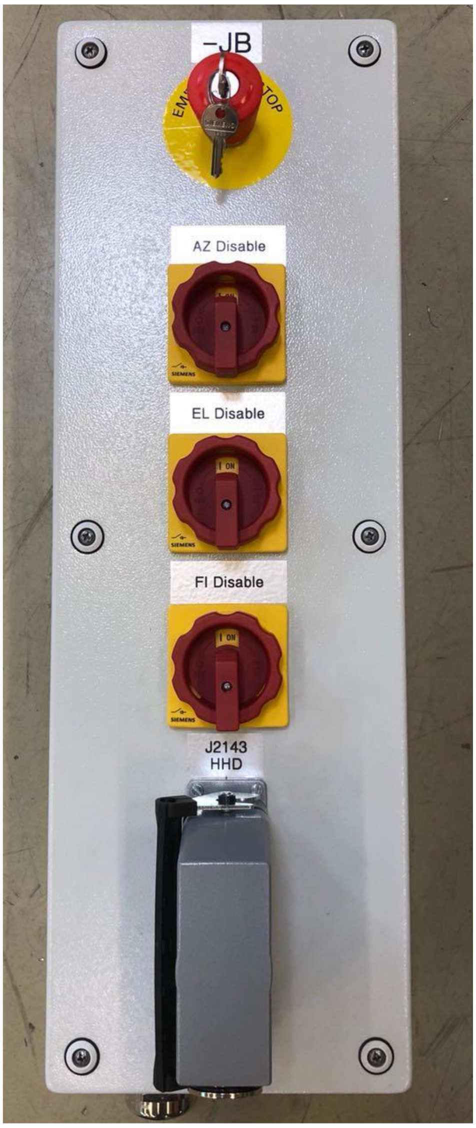


Figure 228: Local Lockout-Tag-Out Box incl. Emergency Stop and HHD Connection Point

Two different operating modes are available for the control system, the operational mode and the engineering mode. The operational mode includes the following general functionalities that are available via the remote interface as well as via LMC:

Operational Modes:

- Stream Tracking (tbc)
  - AZ / EL / Time coefficients streams
- Program Tracking
  - AZ / EL / Time table,
- Pointing Offsets and Corrections (stored in non-volatile memory)
  - AZ, EL, position offsets
  - time offsets based on internal, external or remote clock
- Positioning Modes
  - preset pointing with up to 10 pre-defined positions (e.g. bore-sight, GEOs)
  - parking
  - drive-to-stow

- Manual Control
  - absolute and relative positioning
  - slewing

The engineering (service) mode includes all operational modes and additionally:

- driving the telescope in rate mode (without the usage of the main precision encoders)
- override of interlocks
- driving the telescope beyond the software range of travel

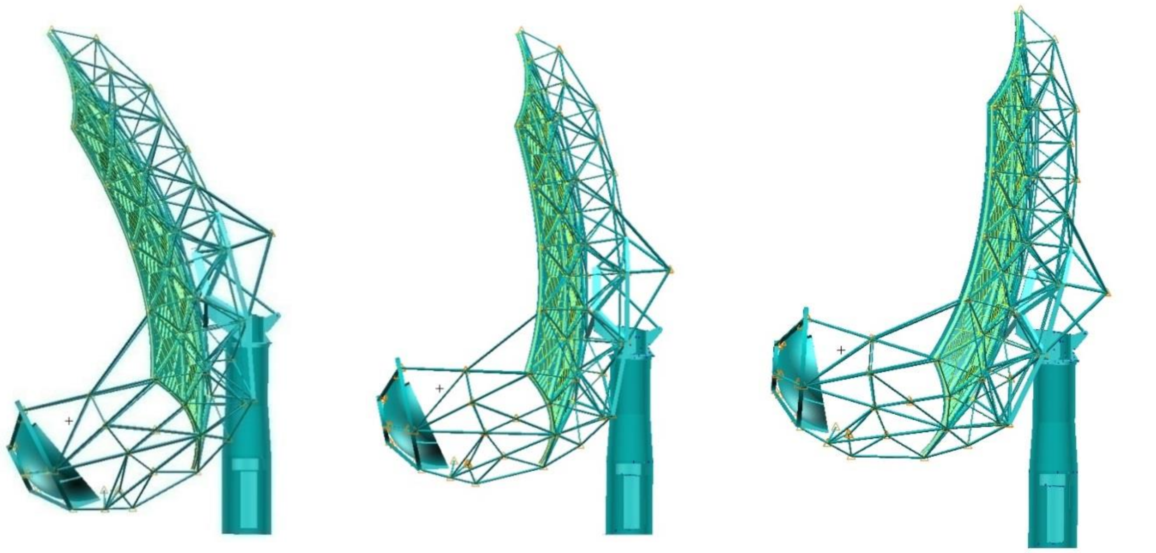
Smooth and save switching between modes with defined priorities is secured by sophisticated control algorithms. Additionally, special modes or concepts could be defined and implemented after mutual interface discussions.

4.2 FE Model and Results

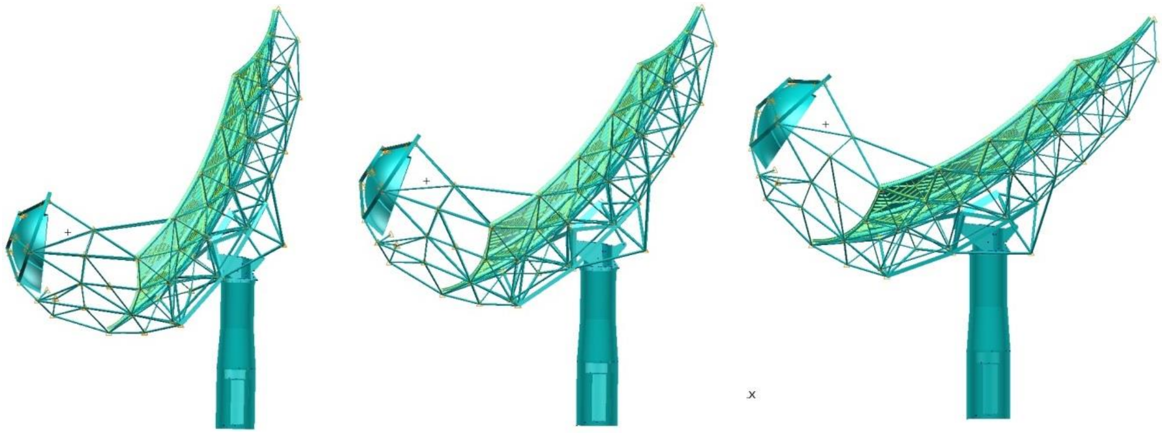
4.2.1 Description of the FE Analysis

4.2.1.1 FE Model

The FE Modeling of the main structure are established, including the main reflector, BUS, interface, knots-mass, adjusters, arm, subreflector, subreflector BUS, extension, indexer-mass, turnhead, pedestal and actuator. FE Models for the reflector at six typical elevation positions are shown in Figure 229. And the detailed view of the model for several local structures are shown in Figure 230. Considering the elevation adjustment of the reflector, several rotation DOFs of the elevation turnhead frame were released (see Figure 231.a). Constrained boundary is added to the elements at the bottom of the model of the pedestal structure, as shown in Figure 231.b. Since the Feed Indexer has only a mass contribution without stiffness during FE analysis of the whole antenna structure, it is modelled as a lumped mass element in the following FE model.

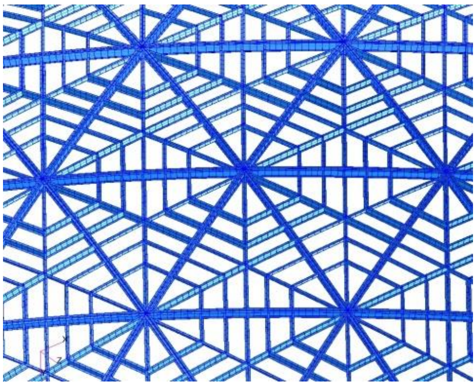


El=15° El=30° El=45°

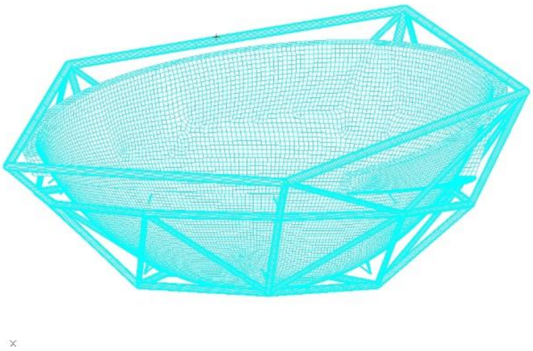


El=60°　　　　　　　　El=75°　　　　　　　　El=90°

Figure 229 FE Models for the reflector at typical elevation positions

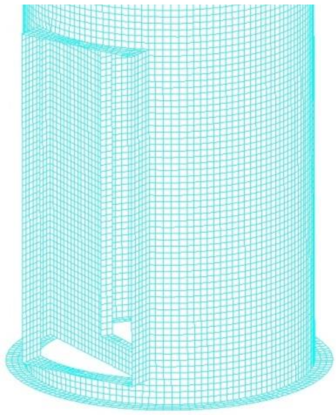


Panel rib



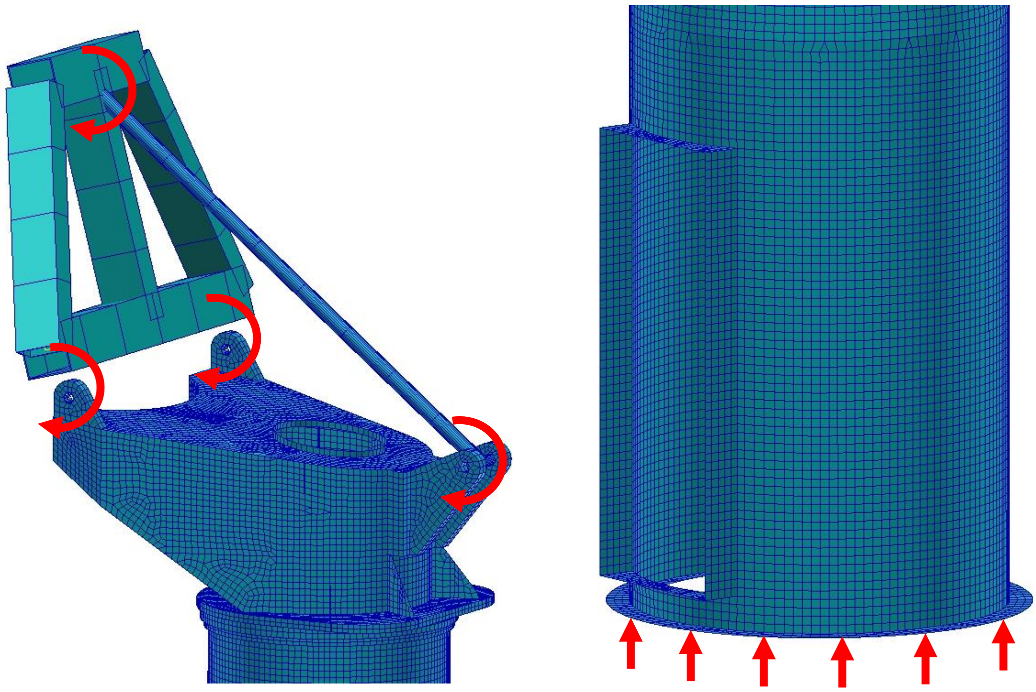
Subreflector

Turnhead



Pedestal

Figure 230 Detailed View of the FE Model for Several Local Structures



a. Release rotary DOF b. Constrained boundary

Figure 231 Constrained boundary

4.2.1.2 Material Properties

Materials involved in the FE model are aluminum alloy, carbon steel and CFRP. The detailed properties are shown in Table 35. And the weight distribution of each level in the model is listed in Table 36.

Table 35 Material Properties used in FEA

Material	Elastic Modulus (GPa)	Density (kg/m^3)	Thermal Expansion Coefficient	Yield Stress (MPa)
Aluminium	70	2.8×10^3	2.3×10^-5	315
Carbon Steel	210	7.8×10^3	1.1×10^-5	345
CFRP Tube	115	1.8×10^3	1.6×10^-6	800
CFRP Shell	90	1.8×10^3	1.6×10^-6	800

Table 36 Weight Distribution in the Model

Level	Item	Component	Weight(kg)	Sum(kg)
Elevation Assembly	Panels	Skins	1059	2578
		ribs	1519	
	Bus	Tubes	6863	7747.2
		Node	827	
		adjuster	57.2	
	Counterweight Assembly	Counterweight Support	449.1	6449.1
		Counterweight	6000	
	Subreflector	Subreflector	112	396.6
		Extension	32.9	
		Sub-bus	83.7	
		Nodes	168	
	Indexer Support	Tubes	267.5	371.5
		Nodes	104	
	Interface	Rectangle Tubes	1091	1091
Indexer	Feeds & Indexer		2000	2000
Actuator	Linear Actuator		594.8	594.8
Pedestal Assembly	yoke		7242	16750
	Pedestal		9508	
Total weight(kg)				37978.2

4.2.1.3 Considered Load Cases

Four kinds of load cases were considered:

a) Gravity is considered in six typical elevation angles mentioned in Figure 229.
b) Mode analysis is carried out.
c) Gradient temperature loaded by the sunshine change is considered. Temperature in the load case can be treated as the difference from the as-built temperature.
d) Wind loads are considered on the whole structure with the main reflector at different azimuth and elevation angles.
e) Strength Analysis is performed under the Dead Load & Survival Wind Load

The above load cases cover the main operating load of the antenna. And the stresses on the structure under these loads are much smaller than the fatigue stress and the critical load of buckling.

4.2.2 FEA Results and Surface Accuracy

Results of each load cases are given as follows. As the surface accuracy of the main reflector would be affected by the deformation, the deformation and surface accuracy under various loads are analyzed respectively, and the strength analysis under the gravity load & survival wind load are also calculated.

4.2.2.1 Deformations under the Gravity Load

Under the gravity load, deformations of the main reflector, the arm structure and the subreflector at each elevation position are shown in Figure 232. Surface accuracy of the main reflector and subreflector under gravity load are shown in Figure 233 and Figure 234, and the total surface accuracy is less than 0.4mm (rms) in whole elevation angle range, as shown in Figure 235.

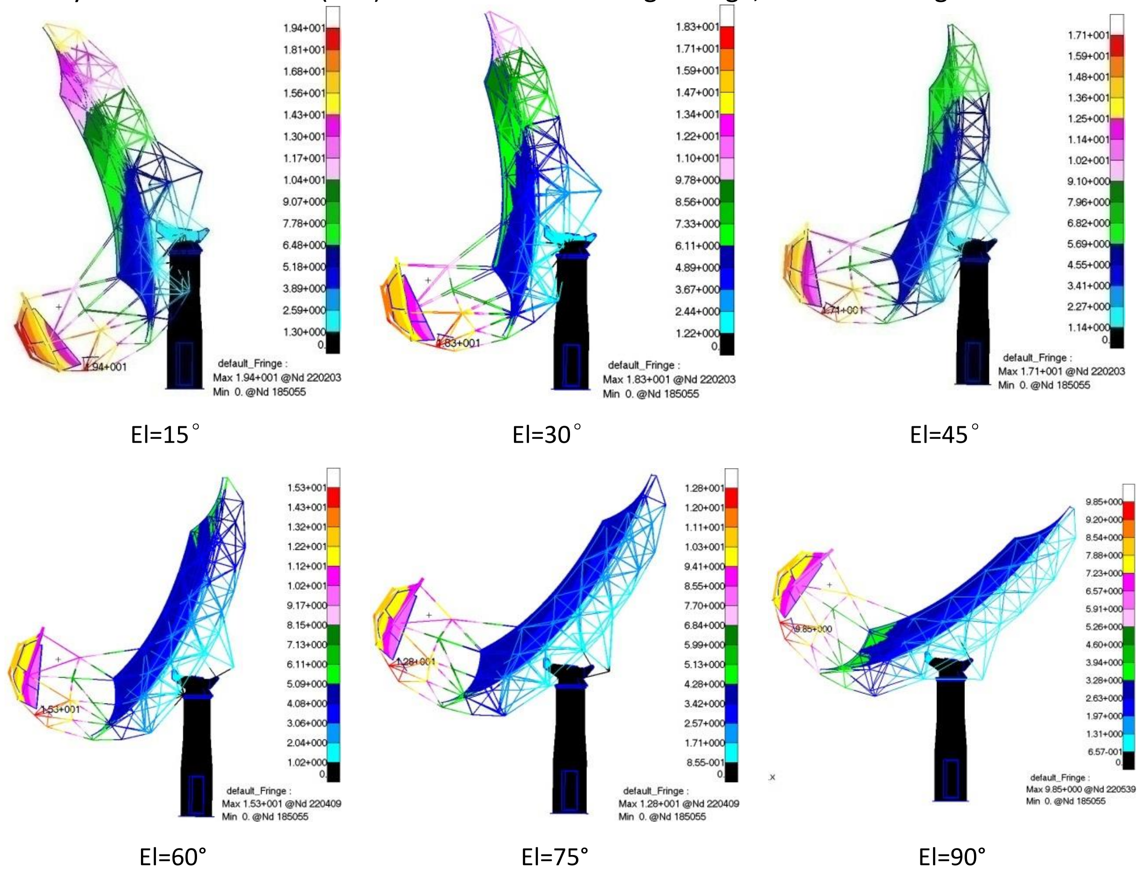


Figure 232 Deformation under the Gravity Load (Unit: mm)

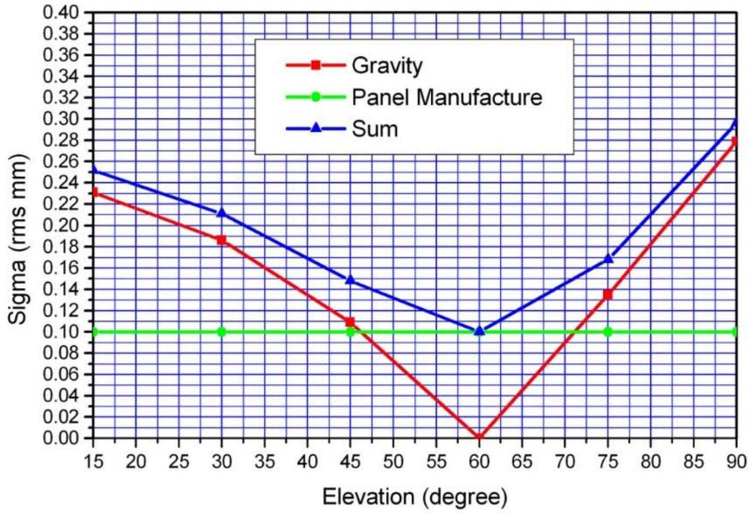


Figure 233 Surface Accuracy of the Main Reflector under Gravity Load

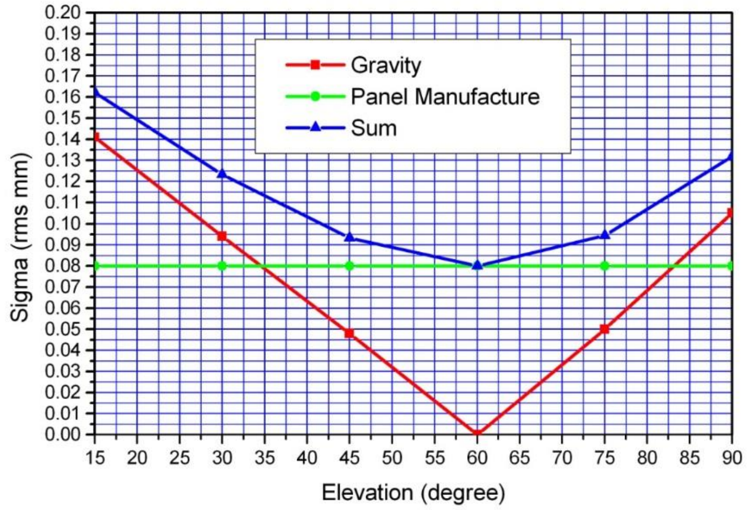


Figure 234 Surface Accuracy of the Subreflector under Gravity Load

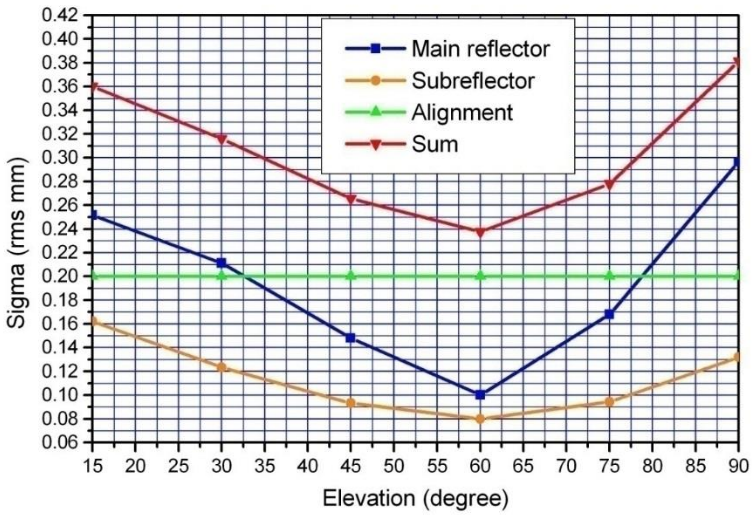


Figure 235 Total Surface Accuracy under Gravity Load

With the consideration of the deformations of the main reflector and subreflector under the gravity load, the model is established in GRASP, as shown in Figure 236. The direction errors of the elevation gain at the 15° and 90° elevation angles are respectively shown in Figure 237 and Figure 238. Based on the total surface accuracy, the reflector phase efficiency of at each elevation angle is calculated by the Ruze formula, as shown in Figure 239.

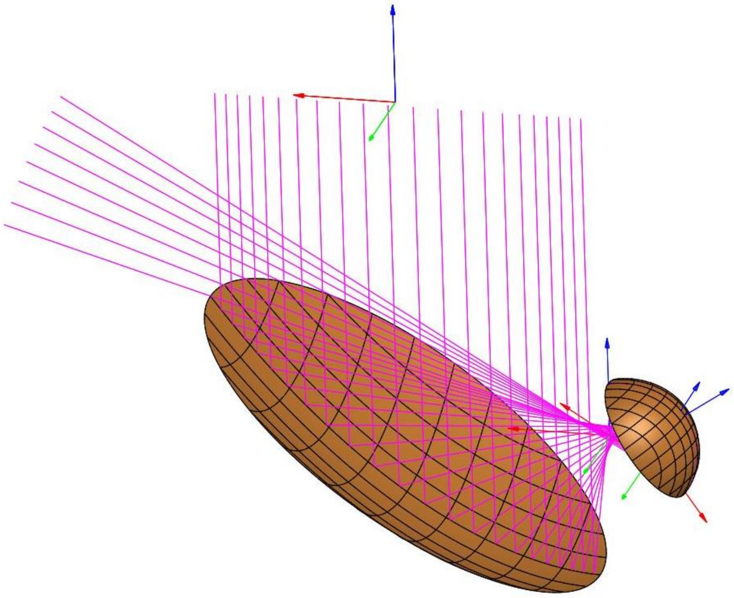


Figure 236 Model in the GRASP with the consideration of the deformation under the gravity load

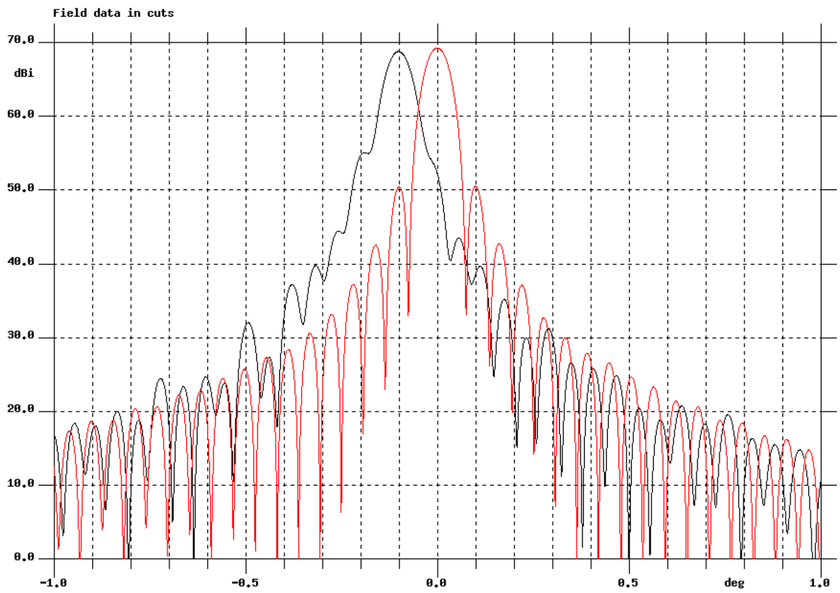


Figure 237 Direction of the Elevation Gain (@El=15°, 20GHz)

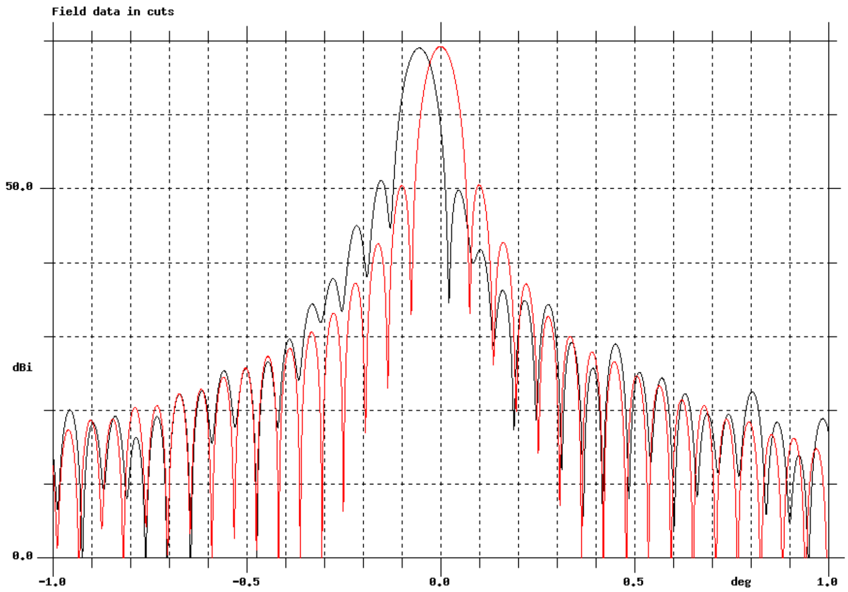


Figure 238 Direction of the Elevation Gain (@El=90°, 20GHz)

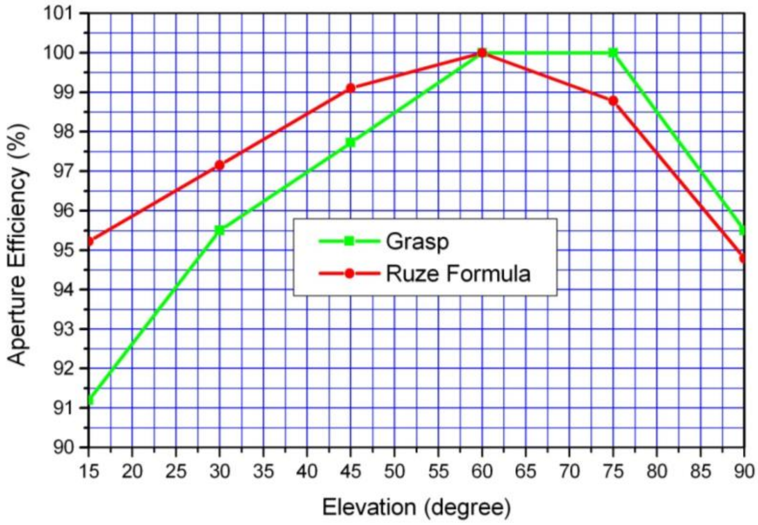
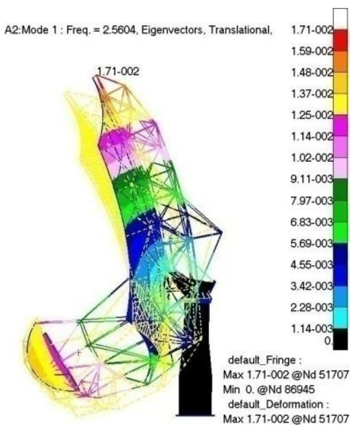
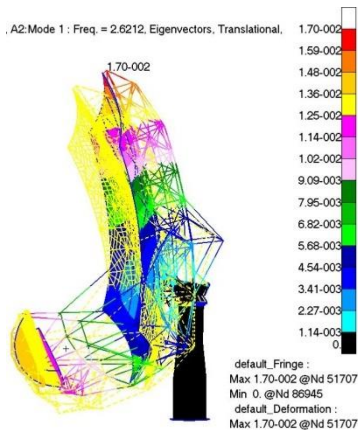


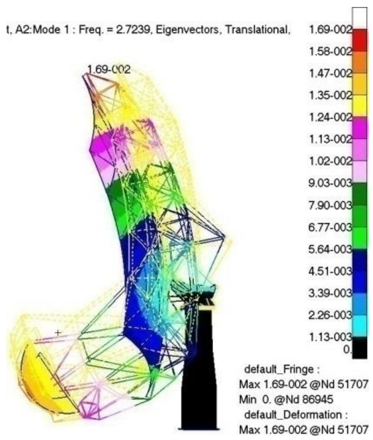
Figure 239 Aperture Efficiency Calculated by the Ruze Formula and GRASP (@20GHz)

4.2.2.2 Mode Analysis Results

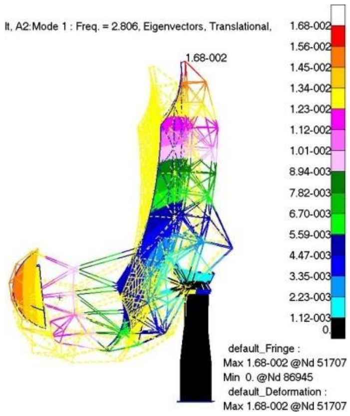
At different elevation angle, mode analysis is performed. First order of the resonant frequency and modal shapes are shown in Figure 240 & Table 37. The first 6 modes of the antenna at El=15° are shown in Figure 241 & Table 38.



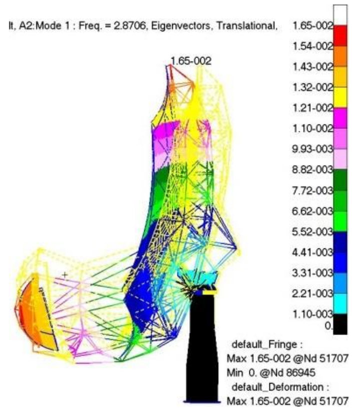




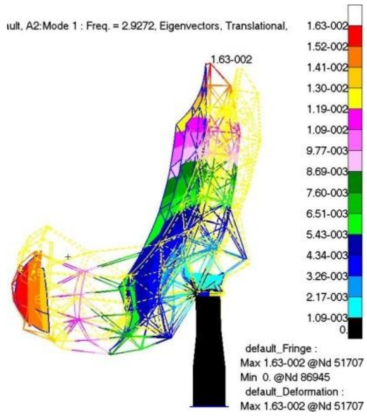
El=15°



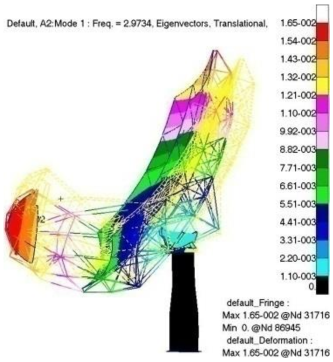
El=20°



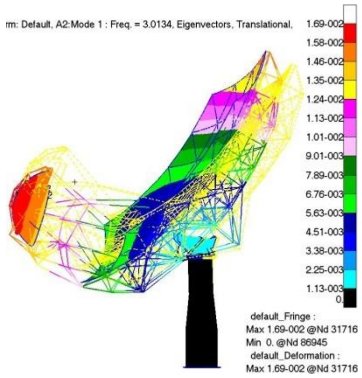
El=30°



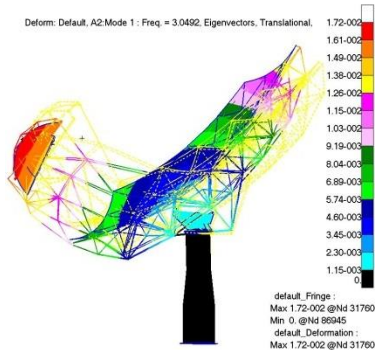
El=40°



El=50°



El=60°

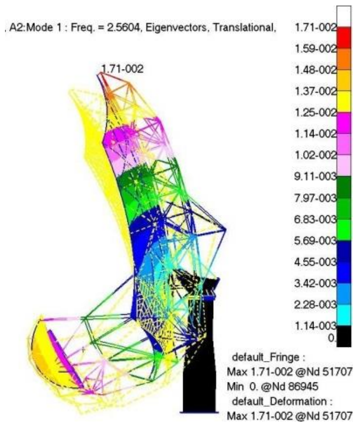


El=70° El=80° El=90°

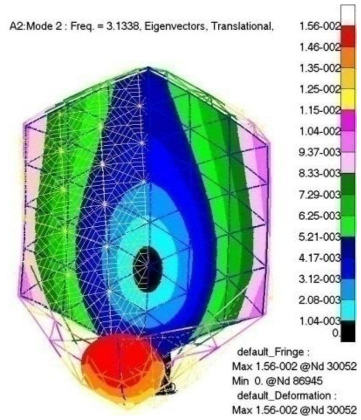
Figure 240 First Mode Results of the Antenna at Different Elevation Positions

Table 37 First Order Resonant Frequencies of the Antenna at Different Elevation Angle

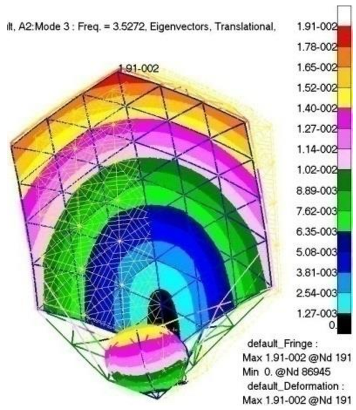
Elevation (degree)	15	20	30	40	50	60	70	80	90
First Order Resonant Frequency (Hz)	2.56	2.62	2.72	2.81	2.87	2.93	2.97	3.01	3.05



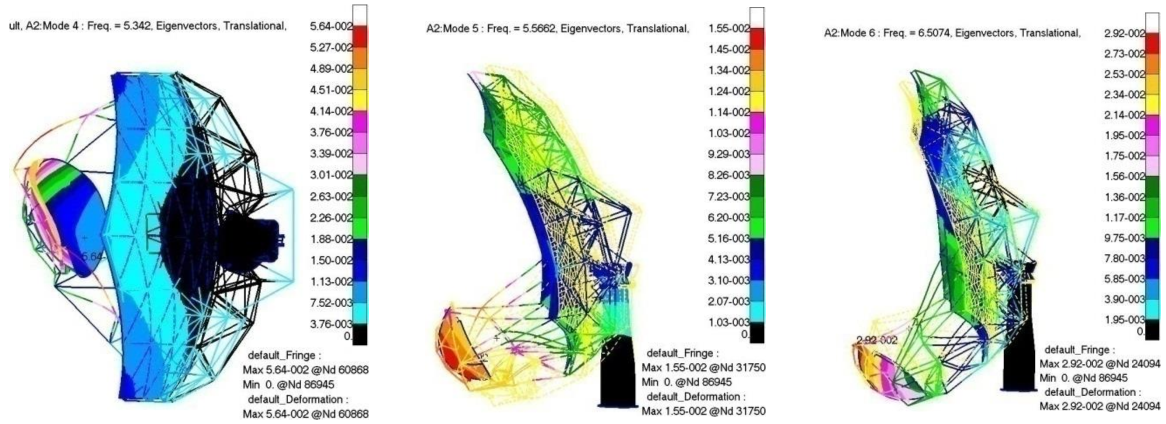
Mode 1



Mode 2



Mode 3



Mode 4 Mode 5 Mode 6

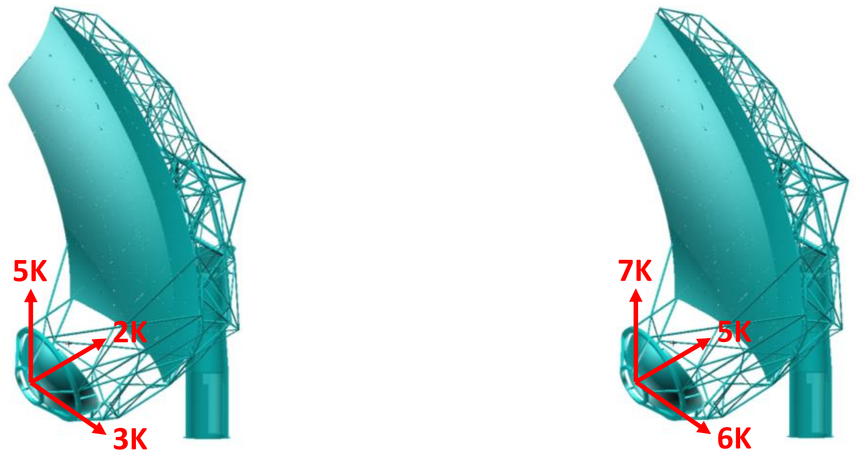
Figure 241 First 6 Modes of the Antenna @ El=15°

Table 38 First 6 Resonant Frequencies of the Antenna at El=15°

Mode @ El=15°	1	2	3	4	5	6
Resonant Frequency (Hz)	2.56	3.13	3.53	5.34	5.57	6.51

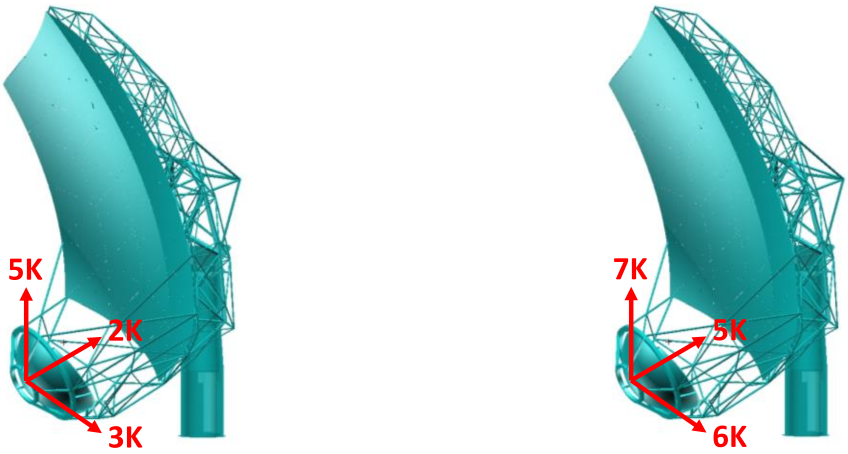
4.2.2.3 Deformations under the Temperature Load

Temperature distribution on the telescope is difficult to determine, since it is related to various factors, including the telescope diameter, position of the sun, surrounding environment, the surface coating and the material thermal property, etc. Besides, it is also relative to the operating state. For example, an antenna at low rotating speeds or in motionless is usually with a great gradient. Considering the solar altitude variation, two kinds of temperature fields with the gradient distribution in three axes shown in



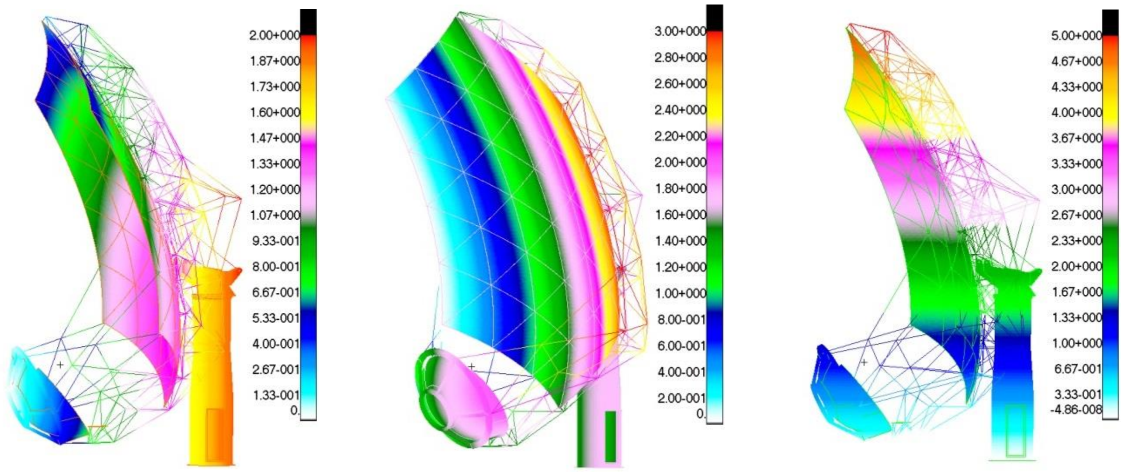
a. Standard Condition b. Degraded Condition

Figure 242, are loaded on the FE model. Deformations of the antenna under the standard condition at three different elevation angles (El=15°/45°/90°) are calculated and shown in Figure 243, Figure 244 & Figure 245. Surface errors caused by the temperature gradient in both conditions are analyzed. The results are shown in Figure 246 - Figure 249.

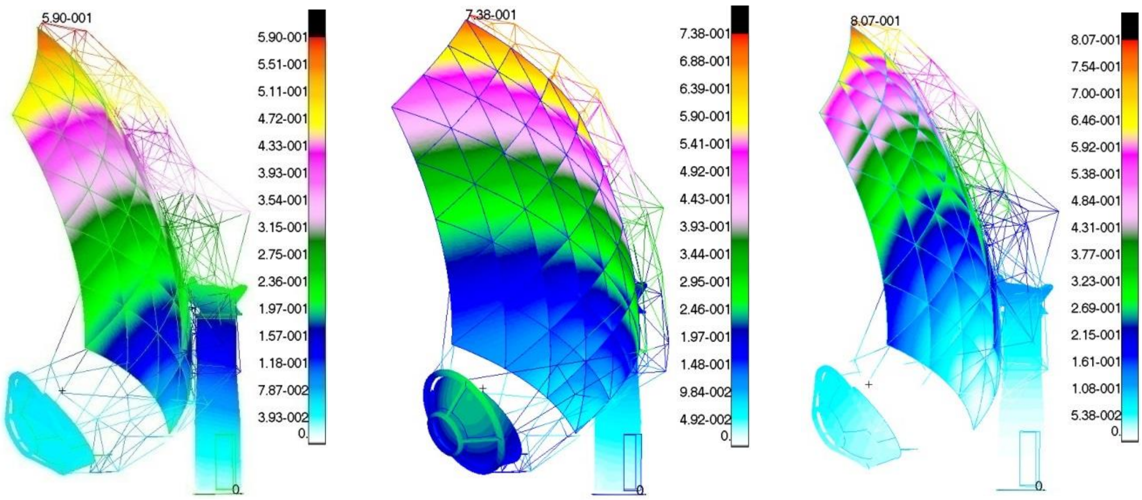


a. Standard Condition b. Degraded Condition

Figure 242 Gradient Temperature Fields in Standard and Degraded Operating Conditions

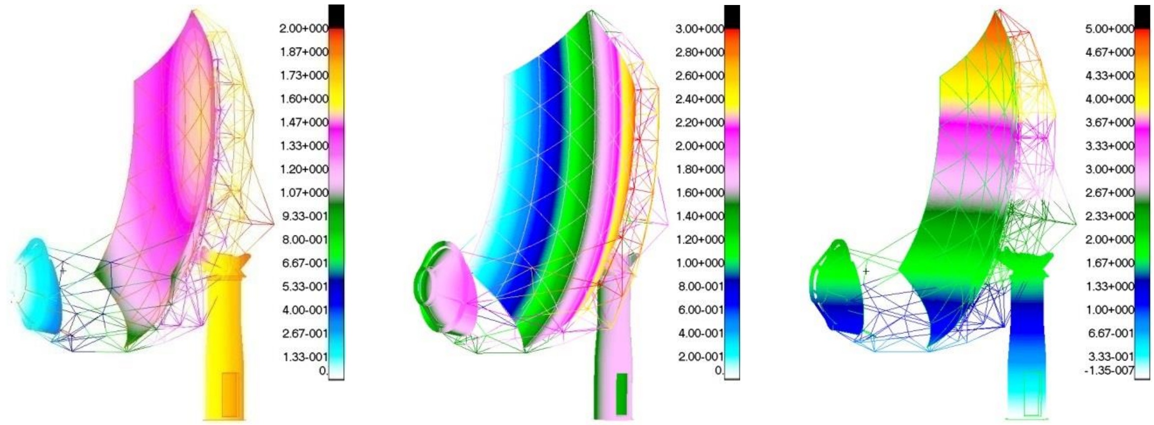


Temperature Gradient 2K Temperature Gradient 3K Temperature Gradient 5K

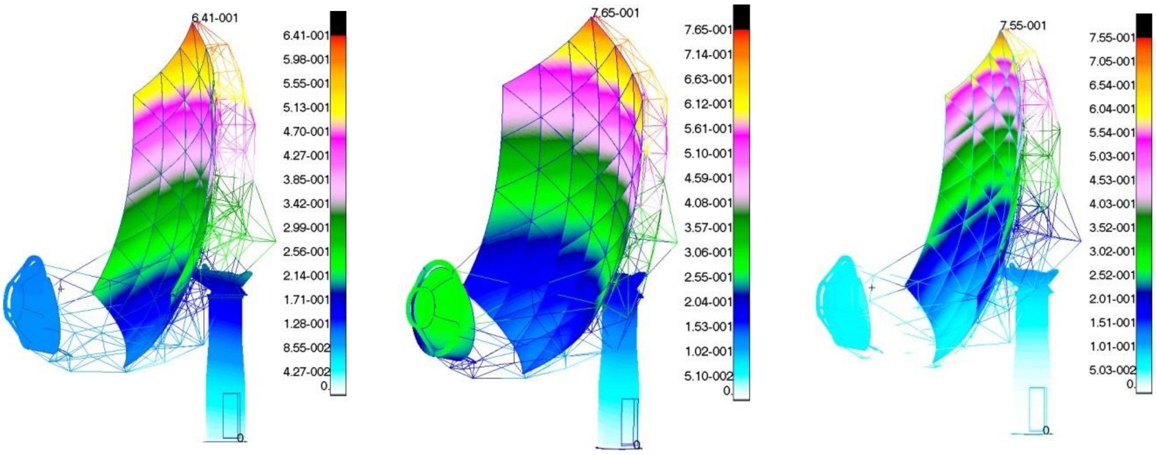


Deformation (2K) Deformation (3K) Deformation (5K)

Figure 243 Temperature Distribution of the Standard Condition and the Corresponding Deformation @ El=15°

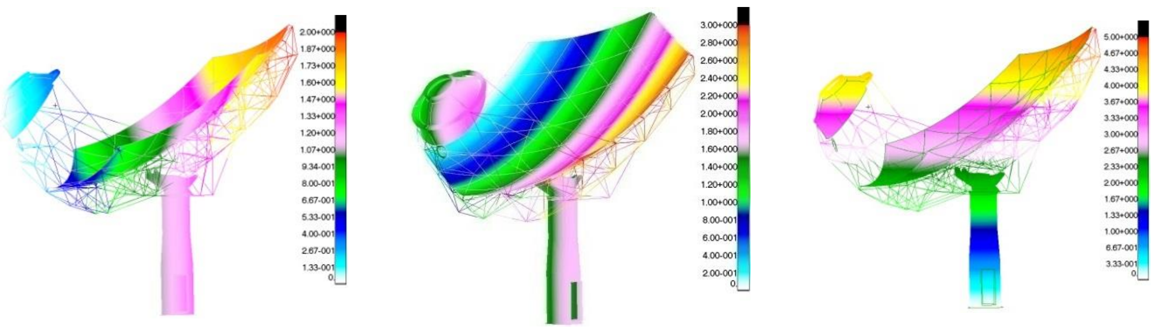


Temperature Gradient 2K Temperature Gradient 3K Temperature Gradient 5K

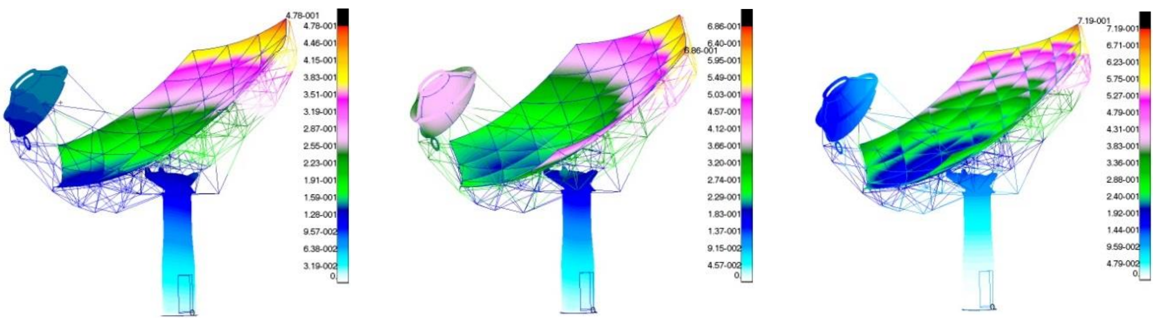


Deformation (2K) Deformation (3K) Deformation (5K)

Figure 244 Temperature Distribution of the Standard Condition and the Corresponding Deformation @ El=45°



Temperature Gradient 2K Temperature Gradient 3K Temperature Gradient 5K



Deformation (2K) Deformation (3K) Deformation (5K)

Figure 245 Temperature Distribution of the Standard Condition and the Corresponding Deformation @ El=90°

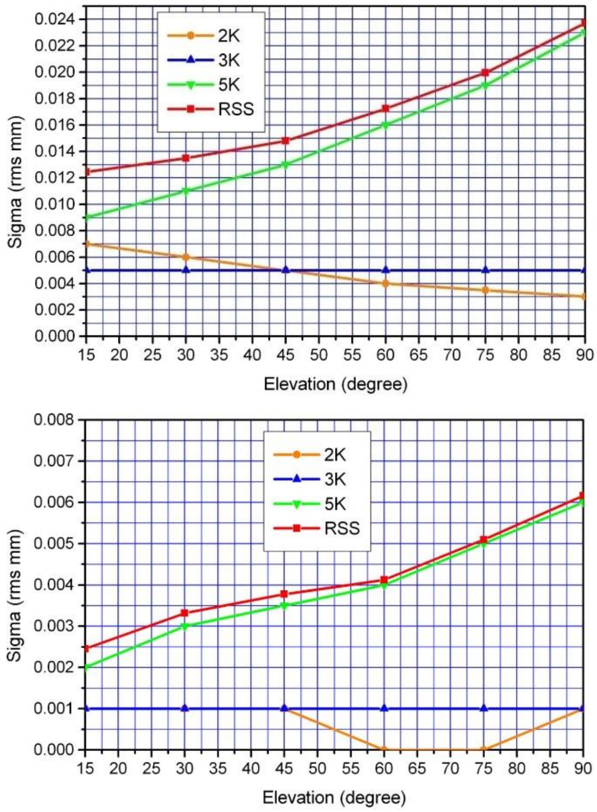


Figure 246 Errors of the Main Reflector and Subreflector under the Standard Temperature Condition

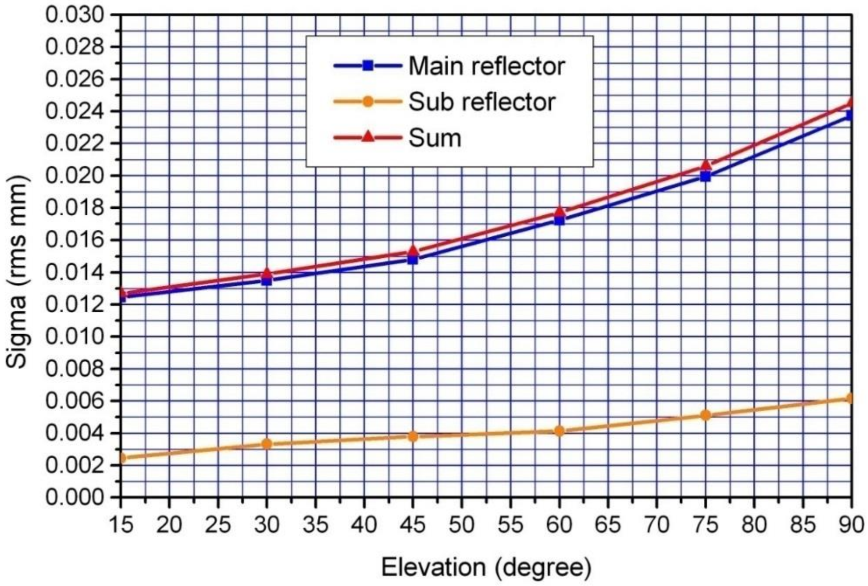


Figure 247 Maximum errors of the Antenna under the Standard Temperature Condition

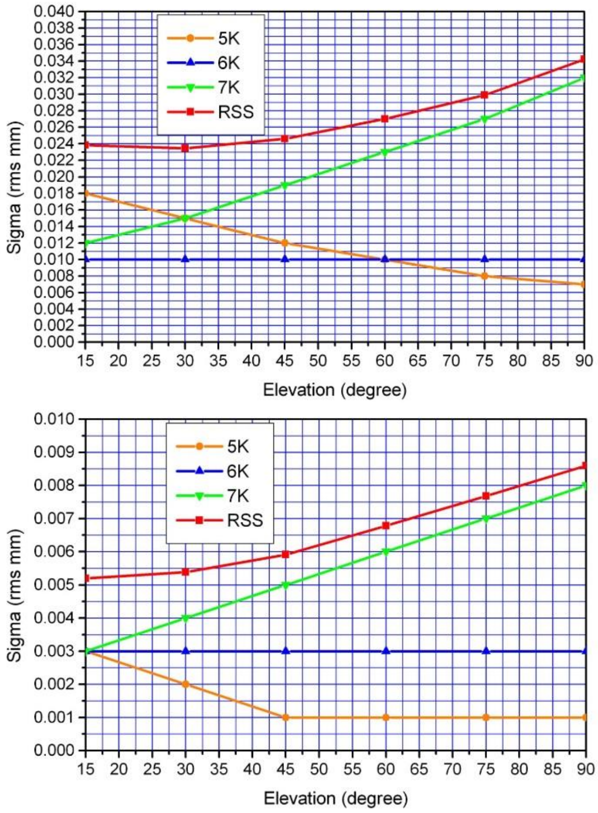


Figure 248 Errors of the Main Reflector and Subreflector under the Degraded Temperature Condition

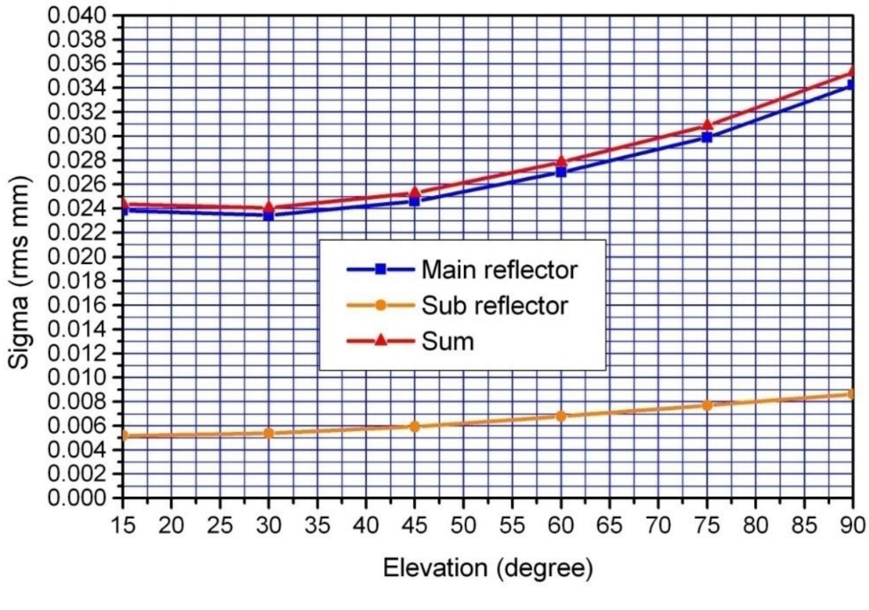


Figure 249 Maximum errors of the Antenna under the Degraded Temperature Condition

4.2.2.4 Surface Accuracy under Wind Loads

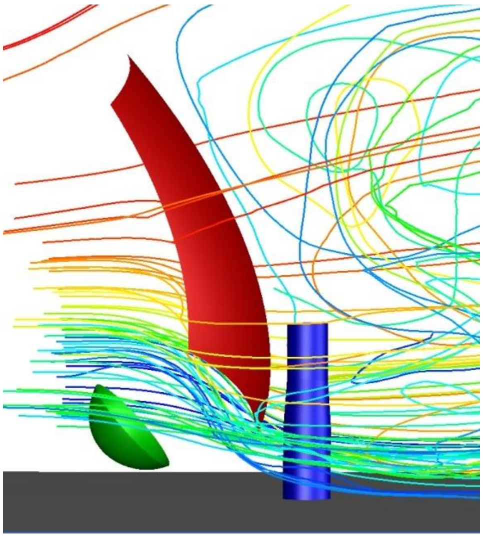
As the wind loads are highly correlated with the angle between the reflector and the wind direction, the pressure distributions on the antenna at the following postures are calculated by CFD analysis.

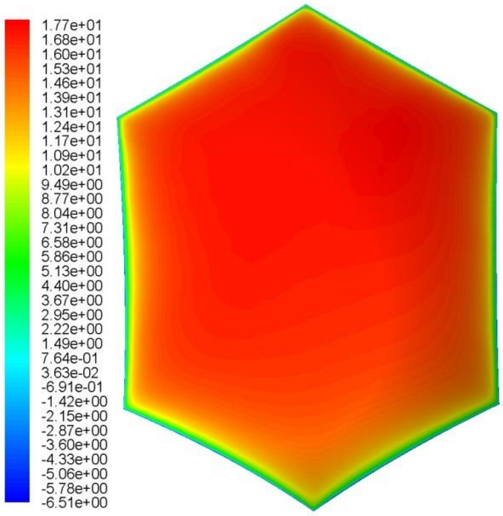
Elevation = 15°/30°/45°/60°/75°/90° @ Azimuth = 0°

Azimuth = 0°/45°/90°/135°/180° @ Elevation = 30°

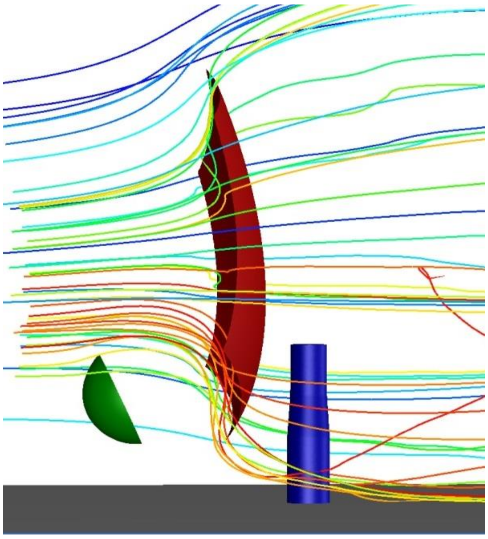
The direction facing the wind is taken as the zero azimuth angle. The flow field and pressure distribution on the front of the main reflectors under each load case are shown in Figure 250 and Figure 251.

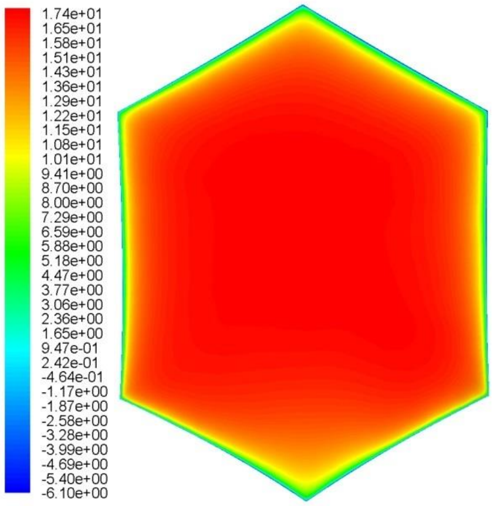
El=15°



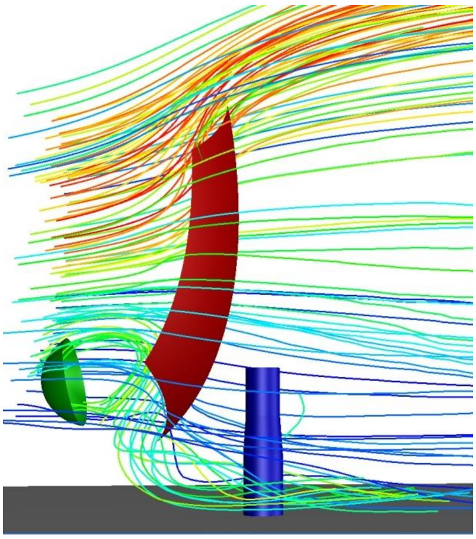


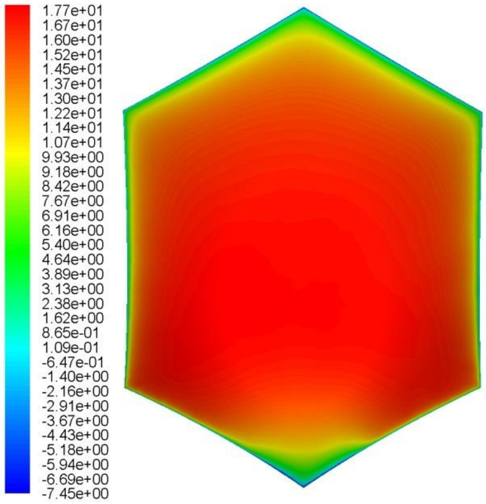
El=30°



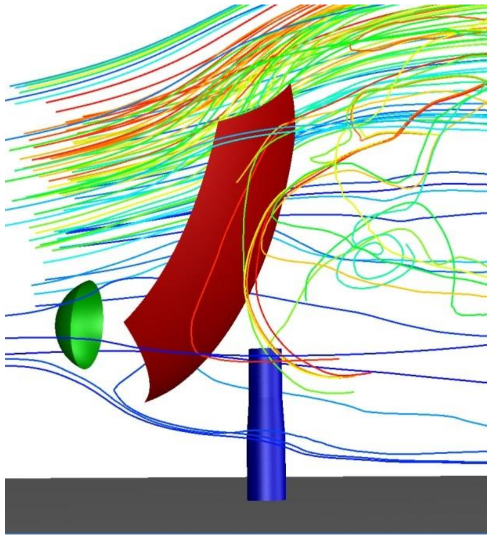


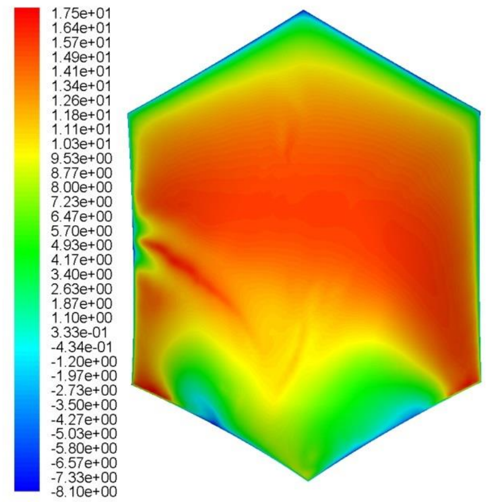
El=45°



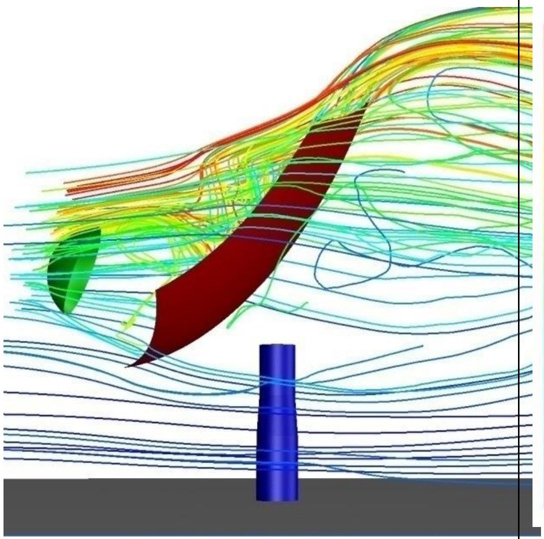


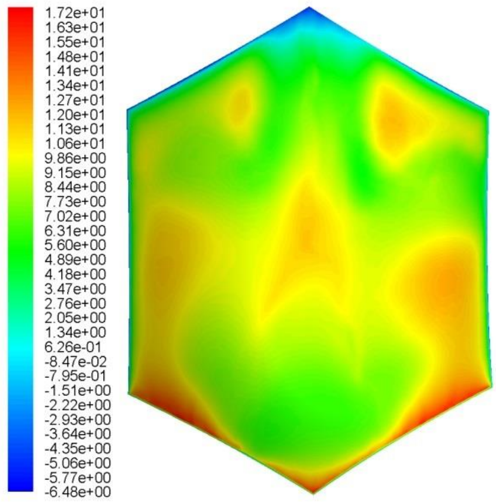
El=60°



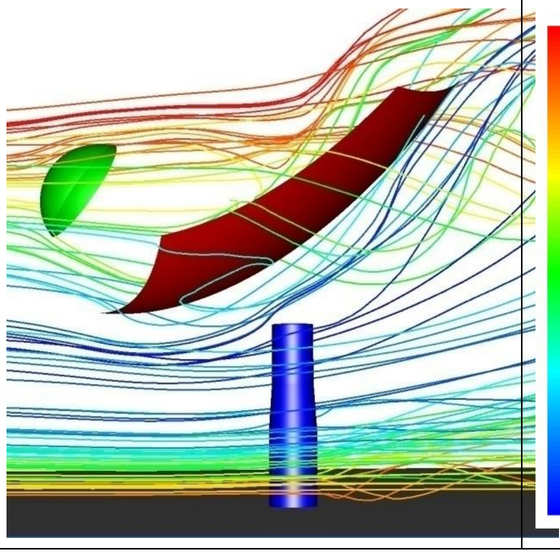


El=75°





El=90°



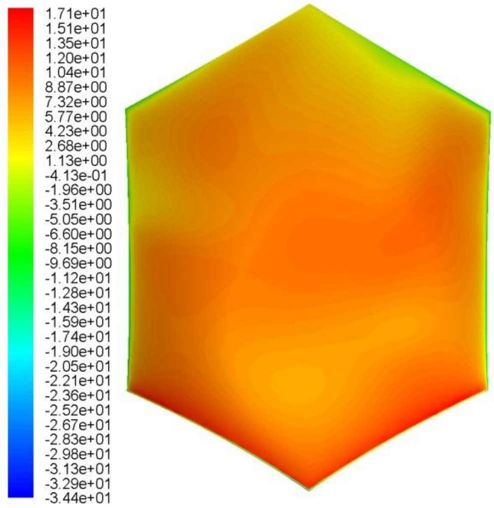
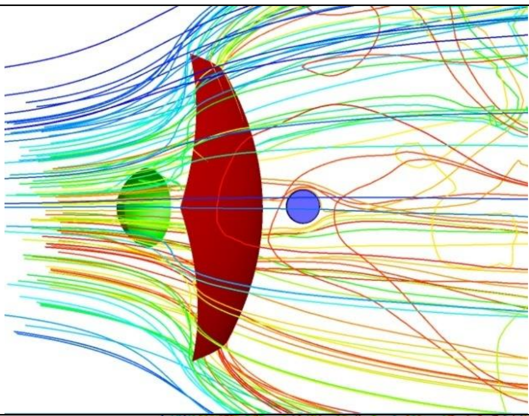
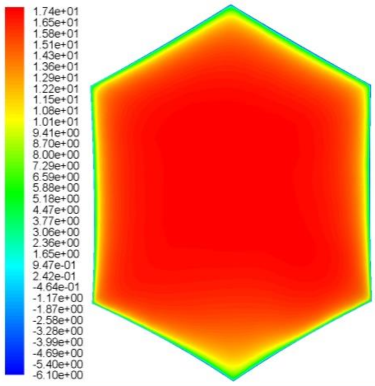
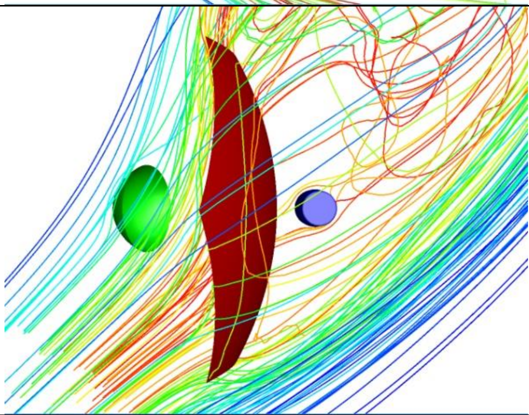
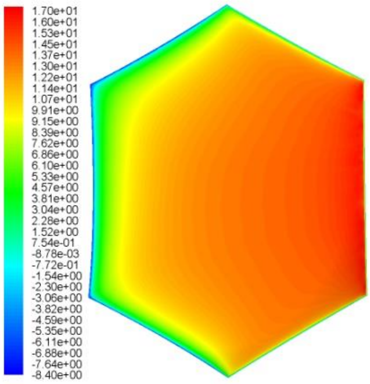
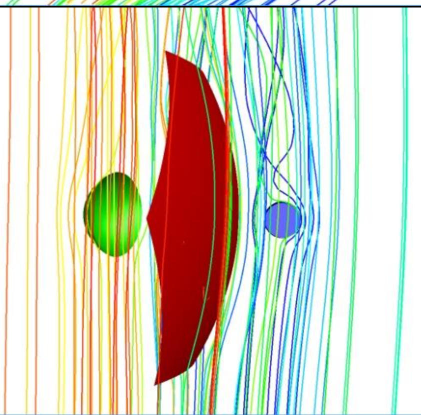
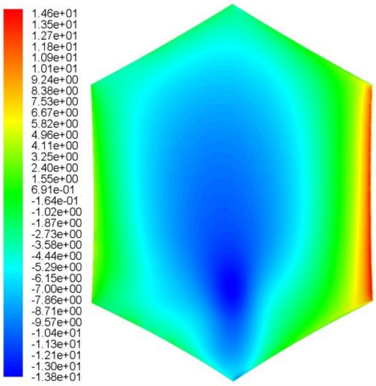
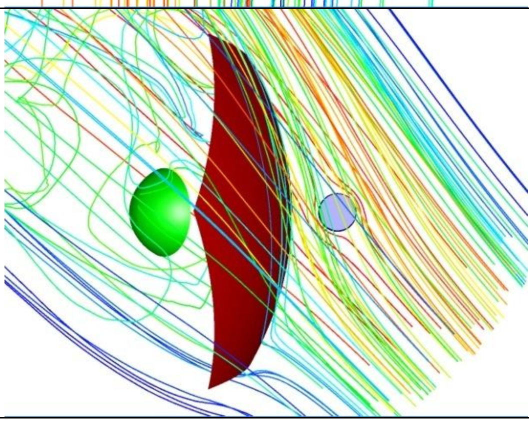
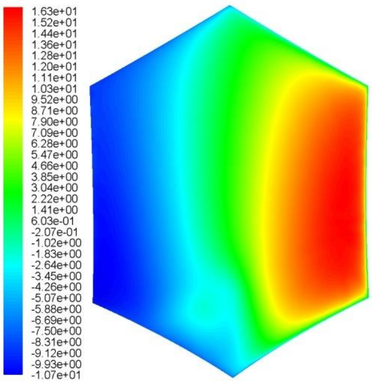


Figure 250 Wind Pressure Distributions on the Antenna at Different Elevations and 0° Azimuth Angle (Unit: Pascal)

<table>
<tr><td>Az=0°</td><td></td><td></td></tr>
<tr><td>Az=45°</td><td></td><td></td></tr>
<tr><td>Az=90°</td><td></td><td></td></tr>
<tr><td>Az=135°</td><td></td><td></td></tr>
</table>

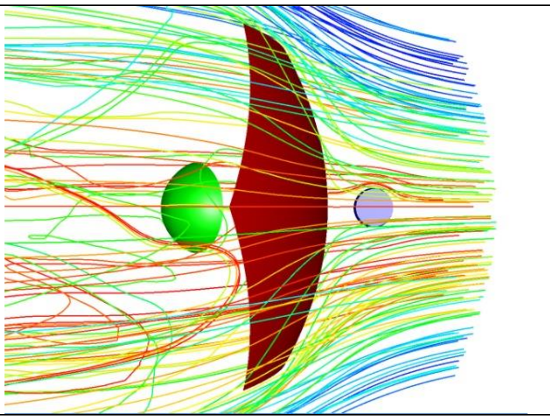
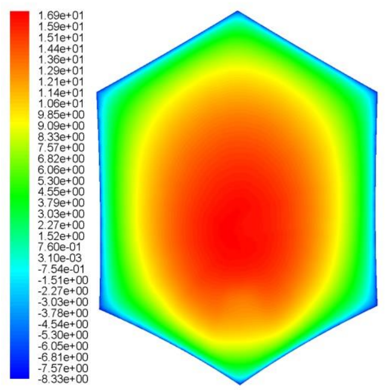
Az=180°		

Figure 251 Wind Pressure Distributions on the Antenna at Different Azimuths and 30°Elevation Angle (Unit: Pascal)

According to the CFD analysis result, the surface accuracy with the deformation is analysed under the winds with three speeds, 5m/s, 7m/s and 10m/s, as shown in Figure 252, Figure 253 and Figure 254.

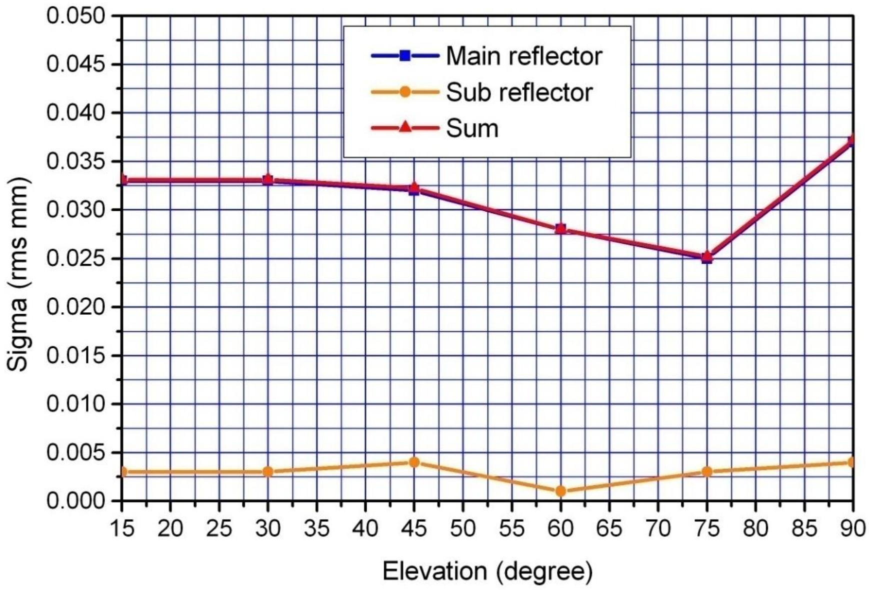


Figure 252 Surface Accuracy at 5m/s Wind Load

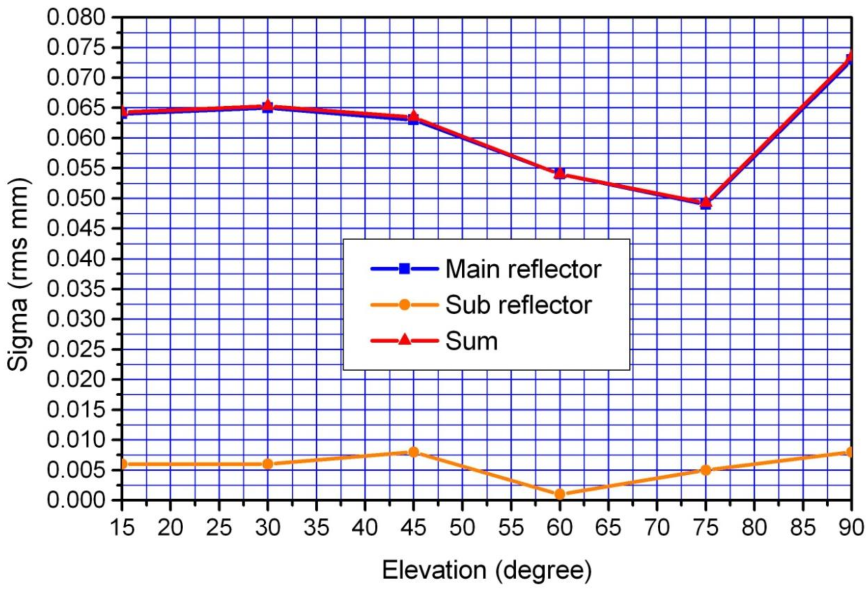


Figure 253 Surface Accuracy at 7m/s Wind Load

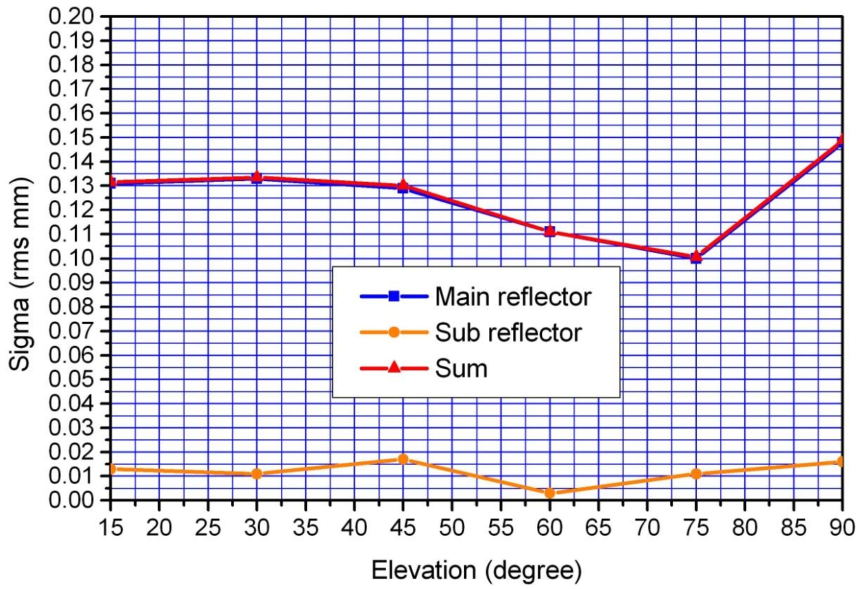


Figure 254 Surface Accuracy at 10m/s Wind Load

4.2.2.5 Total Surface Accuracy Analysis

Load Cases under which surface accuracy is calculated are listed in Table 39 for Precision, Standard and Degraded Operating Conditions. Based on the above results, surface accuracies under different load cases are concluded as follows. Reflector phase efficiency calculated by the Ruze formula under different load cases are shown in Figure 258.

Table 39 Load Cases to calculate the Surface Accuracy

Load Cases	Gravity	Wind Speed	Temperature Gradient
Precision Condition	Yes	5m/s	Standard Condition (2K, 3K & 5K)
Standard Condition	Yes	7m/s	Standard Condition (2K, 3K & 5K)
Degraded Condition	Yes	10m/s	Degraded Condition (5K, 6K & 7K)

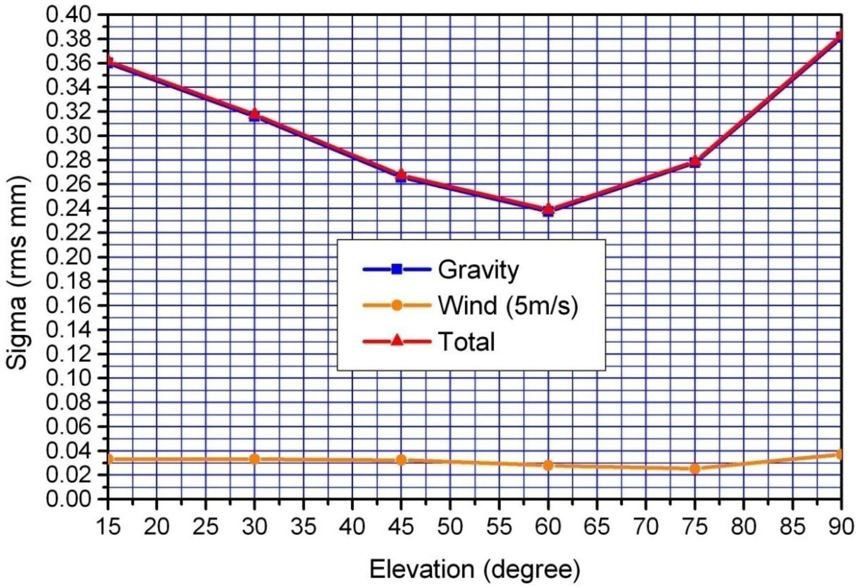


Figure 255 Surface Accuracy in Precision Operating Condition

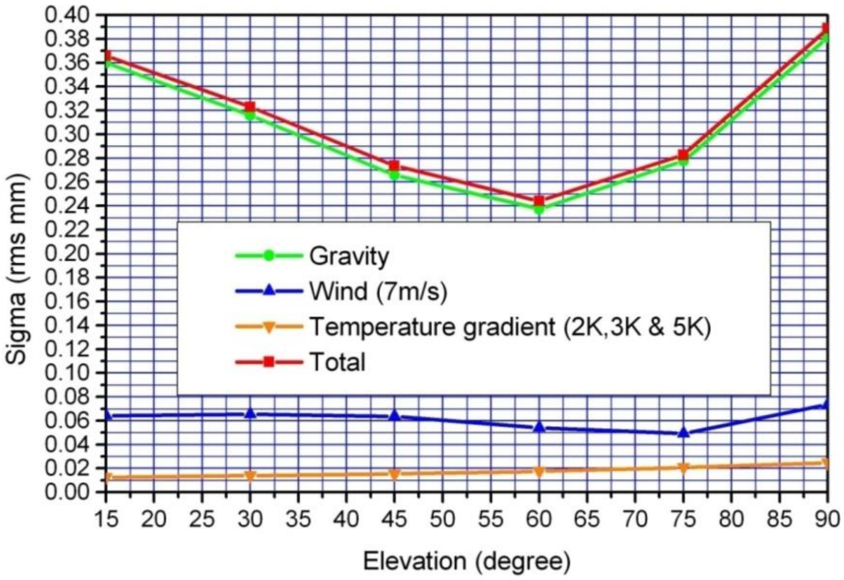


Figure 256 Surface Accuracy in Standard Operating Condition

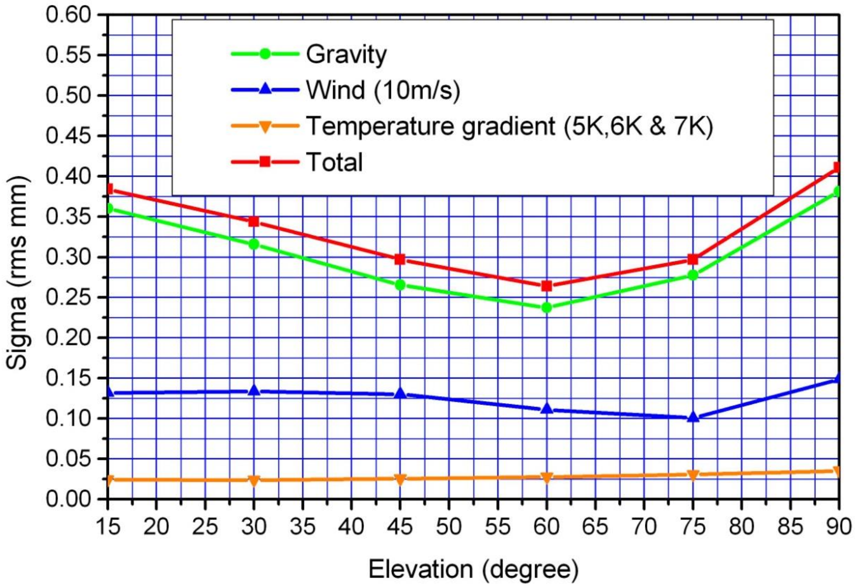


Figure 257 Surface Accuracy in Degraded Operating Condition

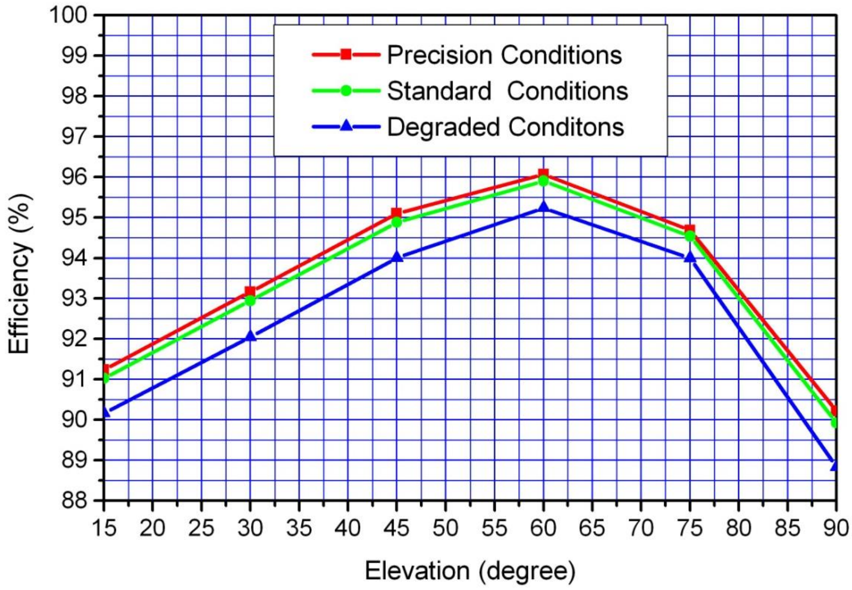


Figure 258 Reflector Phase Efficiency in the Three Operating Conditions (Ruze Formula)

4.2.2.6 Strength Analysis under the Gravity Load & Survival Wind Load (44.4m/s)

Under the survival wind load, pressure distributions on the antenna at the stowed elevation angle (El=90°) is simulated by CFD analysis. The most severe load case is that the main reflector is facing the wind. The results are shown in Figure 259 - Figure 263

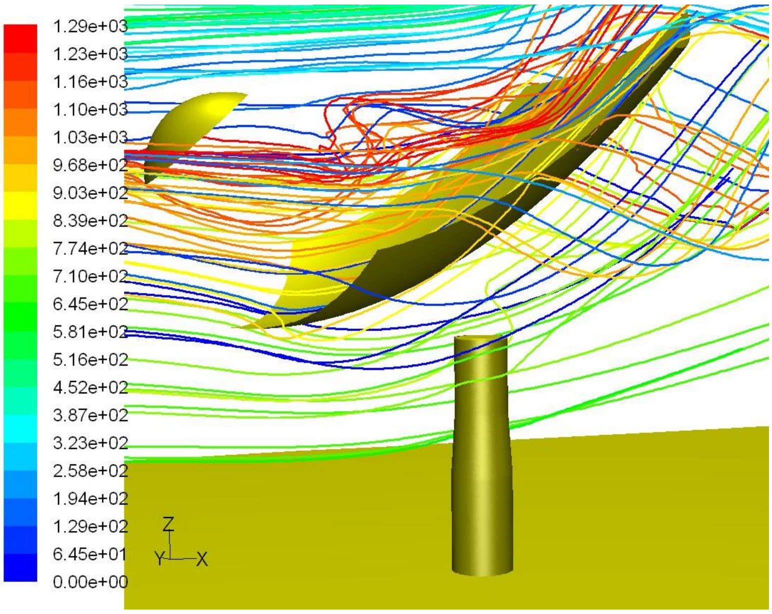


Figure 259 Fluid Path Lines around the Antenna under the Survival Wind Load

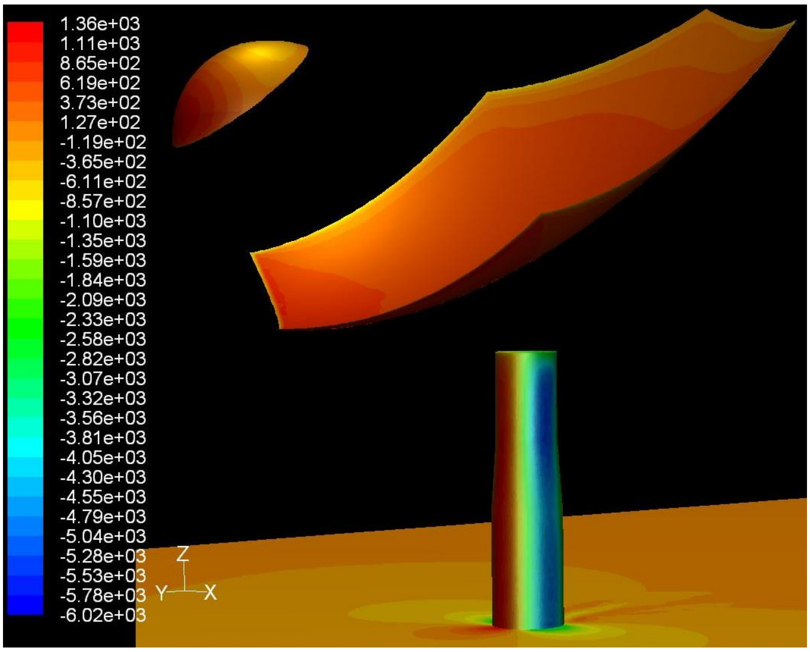
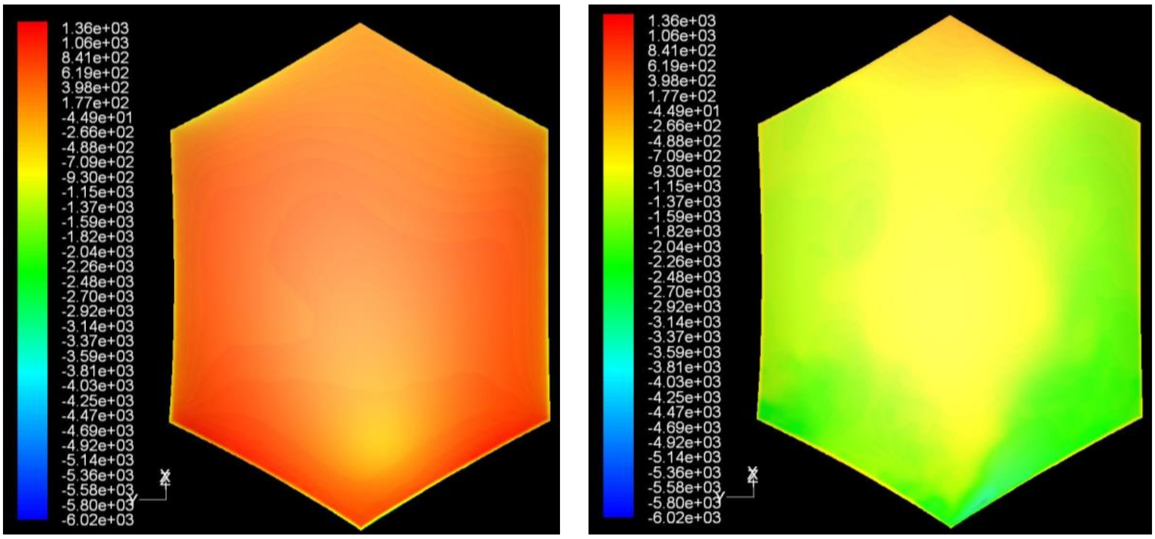
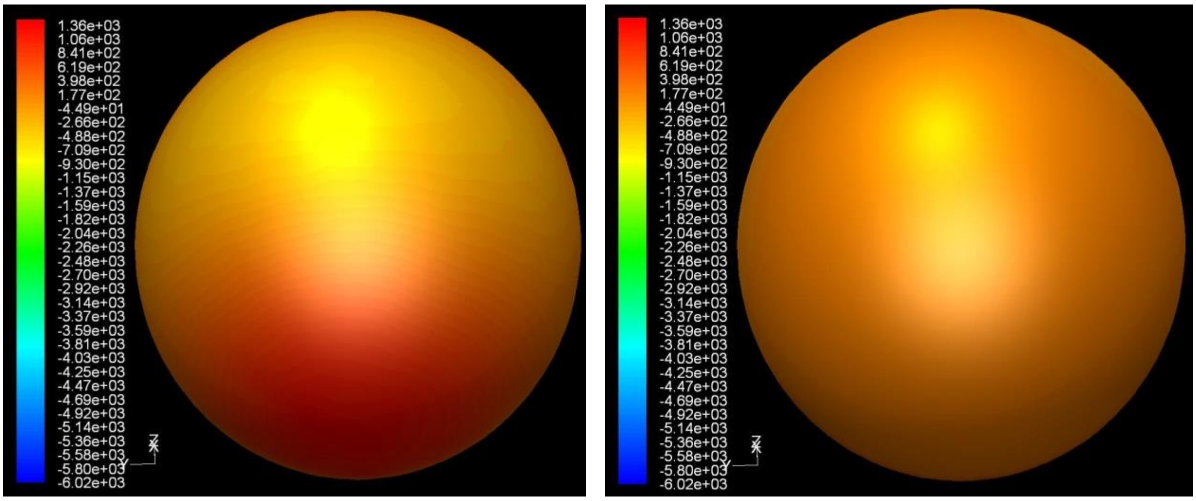


Figure 260 Pressure Contour Map of the Antenna under the Survival Wind Load (Unit: Pascal)



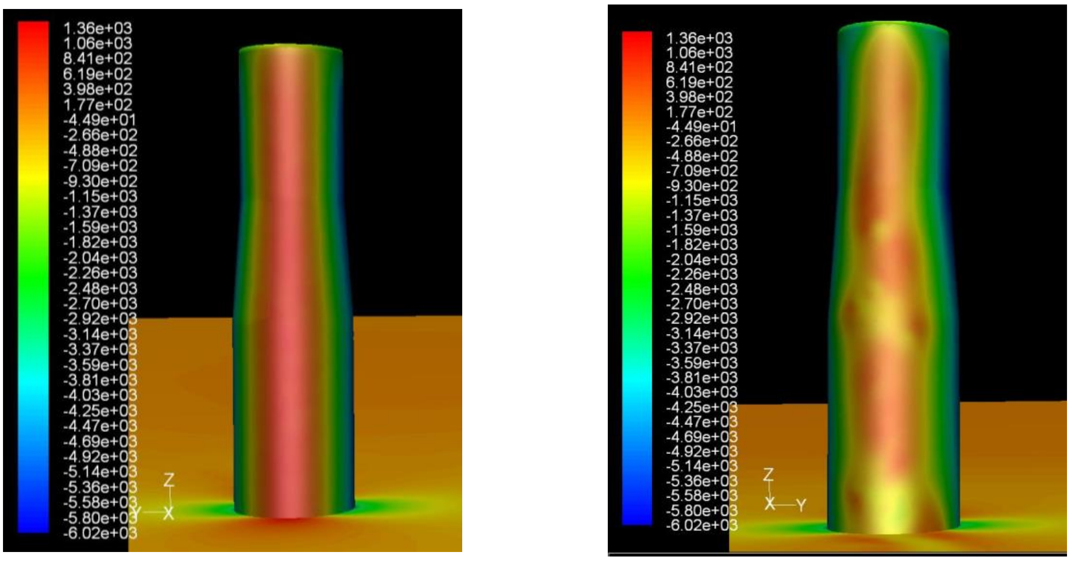
Front Rear

Figure 261 Reflector Pressure Contour Map under the Survival Wind Load (Unit: Pascal)



Front Rear

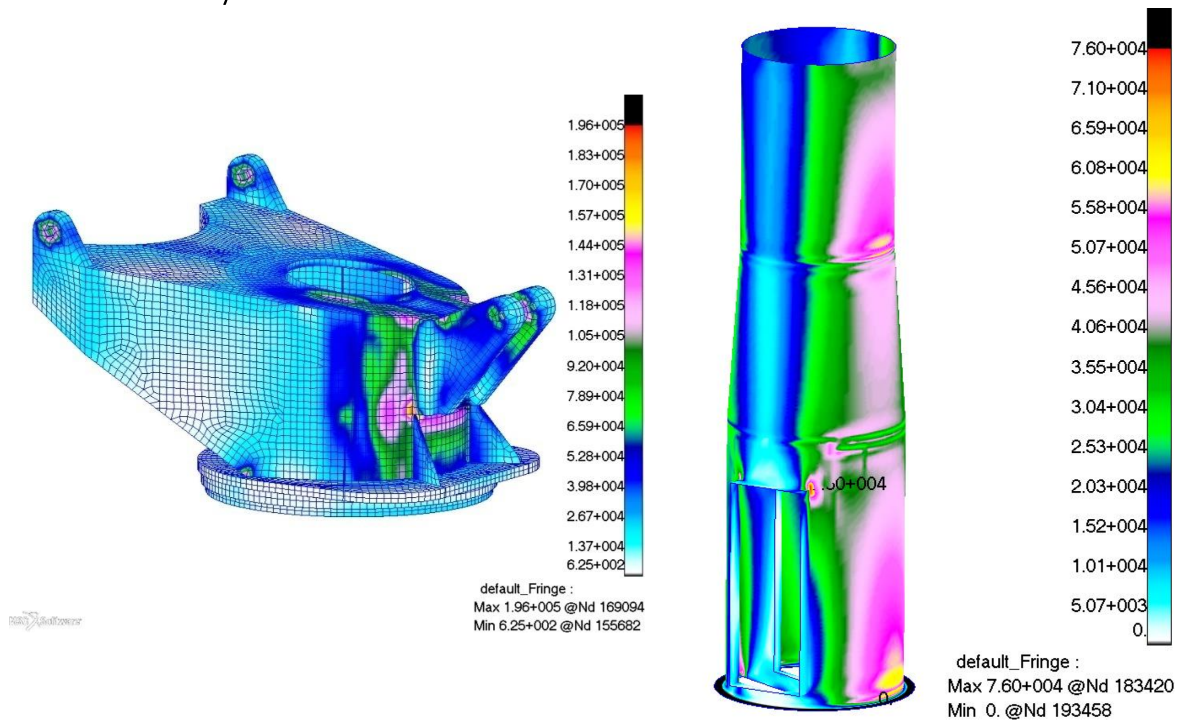
Figure 262 Subreflector Pressure Contour Map under the Survival Wind Load (Unit: Pascal)



Front Rear

Figure 263 Pedestal Pressure Contour Map under the Survival Wind Load (Unit: Pascal)

According to the pressure distribution obtained by CFD analysis, strength analysis of the sensitive parts is performed. Results are shown in Figure 264-Figure 266. It is noted that the stress concentration occurs in Figure 265. Since then, the detailed FE model for the knot structure is established and the stress distribution obtained by the detailed model is obtained, as shown in Figure 266. The maximum stress on each structure is less than the allowable stress. As shown in Figure 266, the maximum stress appears on the end of steel (Q345) chord bar, which is 325MPa and less than the yield limit.



Yoke (Maximum=196MPa) Pedestal (Maximum=76MPa)

Figure 264 Stress Contour Maps on the Yoke and the Pedestal under the Gravity and Survival Wind Load

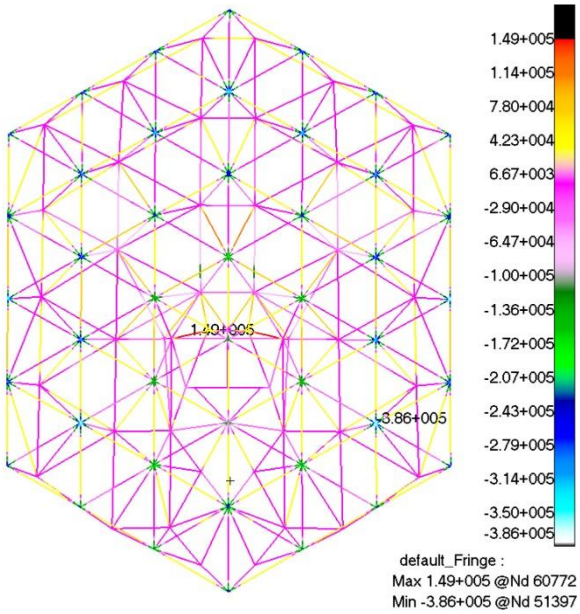


Figure 265 Stress Contour Map on the BUS (Maximum=386MPa)

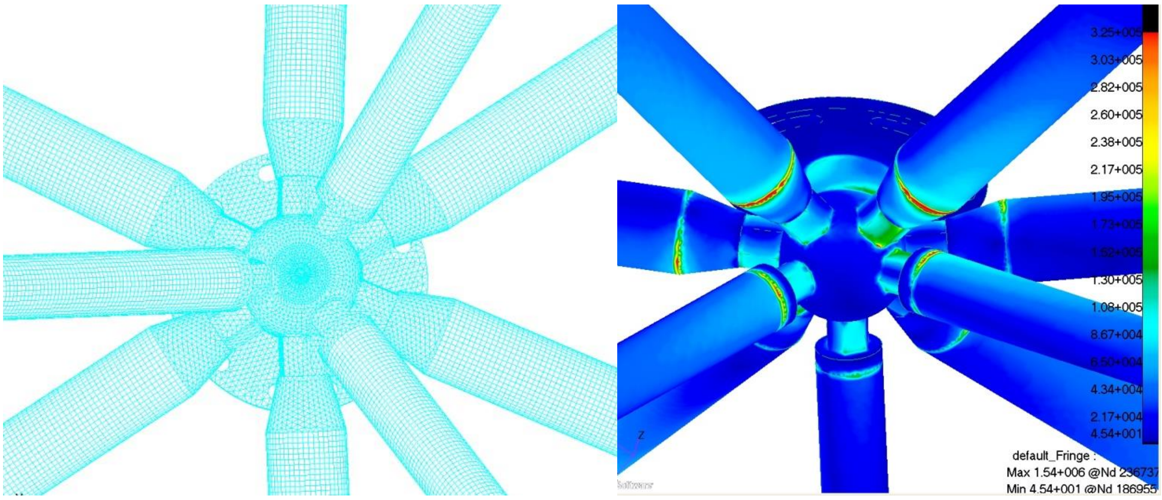


Figure 266 Detailed FE Model for the Knot Structure and the Final Stress Contour Map (Maximum=325MPa)

4.3 Performance Budgets

The requirements of reflector phase efficiency under different operating conditions are specified below:
Under load cases for Precision and Standard Operating Conditions, the dishes element shall have a reflector phase efficiency of > 90% at 15 GHz and > 84% at 20 GHz.
Under load cases for Degraded Operating Conditions, the dishes element shall have a reflector phase efficiency of > 83% at 15 GHz and > 77.3% at 20 GHz.

4.3.1 Radio Reflecting Efficiency

The main reflector adopts aluminium panel, and the subreflector adopts CFRP panel with 140 µm metal layer, so their radio reflecting efficiency is greater than 99.75% over the frequency range of 350MHz to 20GHz, referring to the Section 3.4.3.

4.3.2 Reflector Phase Efficiency

The reflecting surfaces of main reflector and subreflector contribute to the phase efficiency of the reflector. Feed effects are also important on the phase efficiency but are excluded here.
The reflector phase efficiency will be calculated based on the ratio of on-axis gain loss to the undistorted peak gain:

$$\frac{G}{G_0} \approx e^{-\delta^2}$$

δ indicates the phase error and is calculated as below:

$$\delta = 2\Pi \frac{\Delta}{\lambda}$$

Δ is the path length error, which here is a result of surface errors and can be calculated using the formulas:

$$\Delta = 2\sqrt{Ap\ \varepsilon p^2 + As\ \varepsilon s^2}$$

For calculating Ap and As a F/D = 0.5 and e=0.3 (eccentricity of subreflector) has been considered. This results in the following values:
Ap = 0.89 and As = 0.98
εp and εs are the surface error for main reflector and subreflector. The values from the above FE analysis will be used here for accurate analysis.

Table 40 shows the calculated reflector phase efficiency over frequency and elevation angle for different operating conditions:

Table 40: Reflector Phase Efficiency over Frequency and Elevation Angle

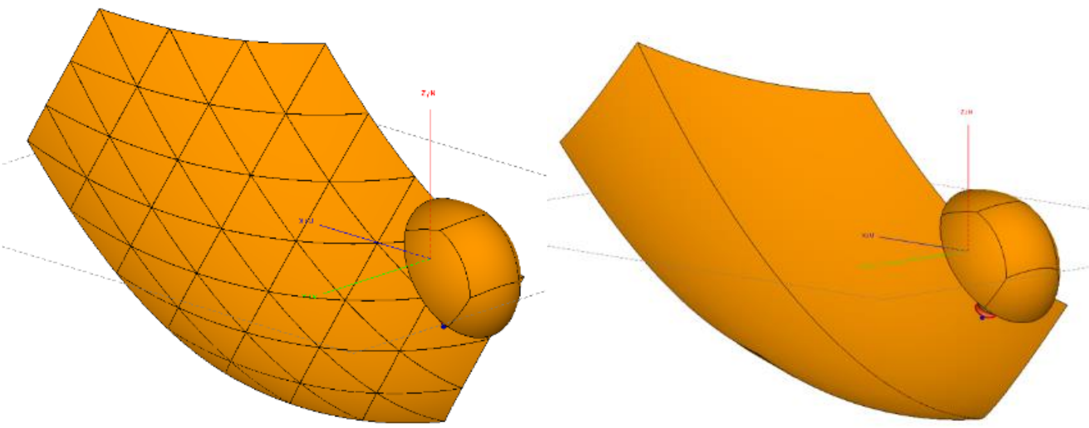
	Input			Reflector Phase Efficiency					
	Temperature			Frequency [MHz]					
	Wind [m/s]	Gradient [K]	Elevation	350	3000	8000	1000	15000	20000
Precision	5m/s	(2K, 3K, 5K)	15°	100.00%	99.87%	99.07%	98.55%	96.77%	94.32%
			30°	100.00%	99.89%	99.24%	98.82%	97.37%	95.37%
			60°	100.00%	99.97%	99.82%	99.72%	99.38%	98.89%
			90°	100.00%	99.84%	98.89%	98.27%	96.16%	**93.27%**
Standard	7m/s	(2K, 3K, 5K)	15°	100.00%	99.86%	99.04%	98.50%	96.66%	94.13%
			30°	100.00%	99.89%	99.21%	98.77%	97.25%	95.17%
			60°	100.00%	99.97%	99.80%	99.68%	99.29%	98.74%
			90°	100.00%	99.84%	98.85%	98.20%	96.00%	**93.01%**
Degraded	10m/s	(5K, 6K, 7K)	15°	100.00%	99.84%	98.90%	98.29%	96.20%	93.34%
			30°	100.00%	99.87%	99.07%	98.55%	96.76%	94.32%
			60°	100.00%	99.96%	99.70%	99.53%	98.95%	98.15%
			90°	100.00%	99.81%	98.67%	97.93%	95.40%	**91.97%**

FromTable 40, it can be seen that the calculated results meet the requirements.

4.3.3 Leakage through Reflector

4.3.3.1 Leakage through Main Reflector

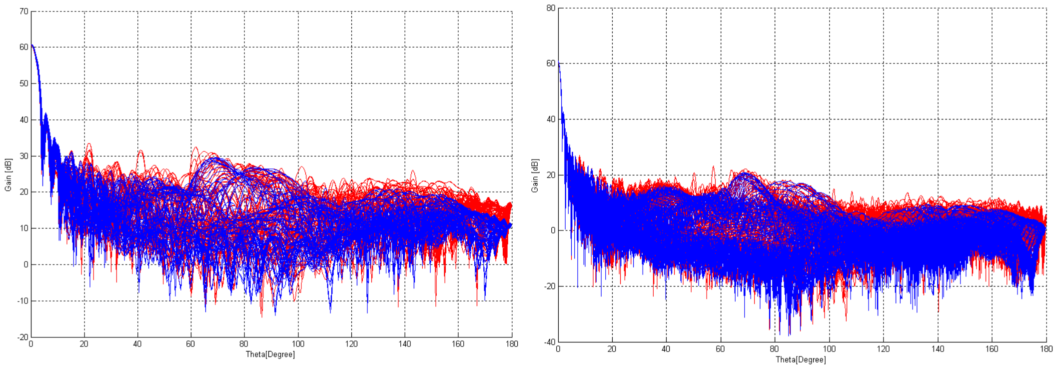
The main reflector consists of 66 aluminum panels with 3 mm gaps width. Part of the electromagnetic wave incident on the main reflector will transmit through the gaps. To evaluate this effect, full-wave simulations are carried out. Figure 267 shows the paneled dish model built in FEKO, and for comparison, an ideal main reflector without gap is also built and simulated. Please note the black lines in each subreflector and the main reflector of (b) are due to the software and do not stand for gaps.



(a) Model of Main Reflector with Gaps **(b) Model of Main Reflector without Gaps**

Figure 267: Dish Model Built in FEKO

The radiation pattern comparisons at 350MHz and 1.0GHz are shown in Figure 268. It can be seen that the paneled main reflector leads to higher side lobes and the difference between two conditions becomes smaller at higher frequencies.



(a) Patterns 350MHz **(b) Patterns at 1.0GHz**

Figure 268: The radiation pattern comparisons between main reflector with and without gaps

In order to estimate the energy leakage through the main reflector, the ratio of side lobe energy behind the main reflector to the full pattern energy at several frequencies are calculated, and the results are shown in Figure 269.

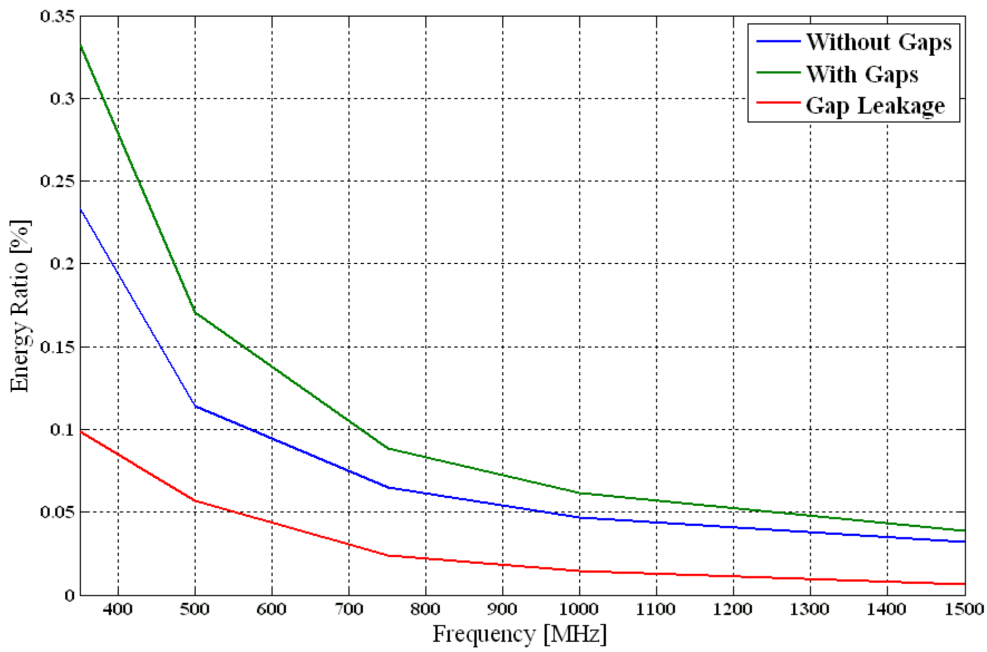


Figure 269: Energy Ratio of the Side Lobes Behind the Main Reflector

From Figure 269, it can be seen that the leakage through the gaps (red line) decreases with the frequency, and the maximum ratio to the total energy radiated at 350 MHz is below 0.1%.

4.3.3.2 Leakage through Subreflector

The sub-reflector consists of one central panel and five panels in the outer ring, with 1mm gaps width. To evaluate the gaps' effect, full-wave simulations are carried out using FEKO software. Three models are built in FEKO: Side coated (SC), Reflecting Surface Expended & Side coated (RSE&SC), and Side uncoated (SU), as shown in Figure 270.

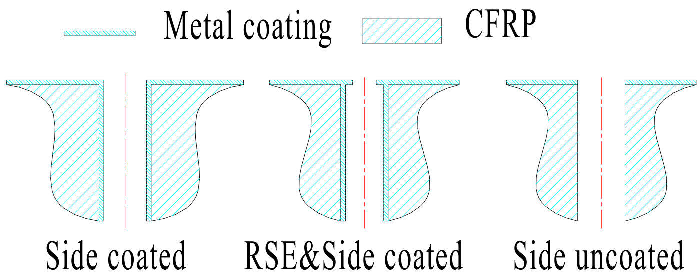


Figure 270 Sub-reflector panel model with three types of metal coating.

The scattering pattern of the paneled sub-reflector illuminated by a corrugated horn is simulated, and the energy ratio of the scattering pattern behind the sub-reflector to the full pattern is calculated. Since the effect of panel gaps is more significant at low frequency, the energy ratio is calculated at 350MHz, 500MHz, 750MHz, and 1000MHz. The calculated results for both vertical and horizontal polarizations are shown in Figure 271

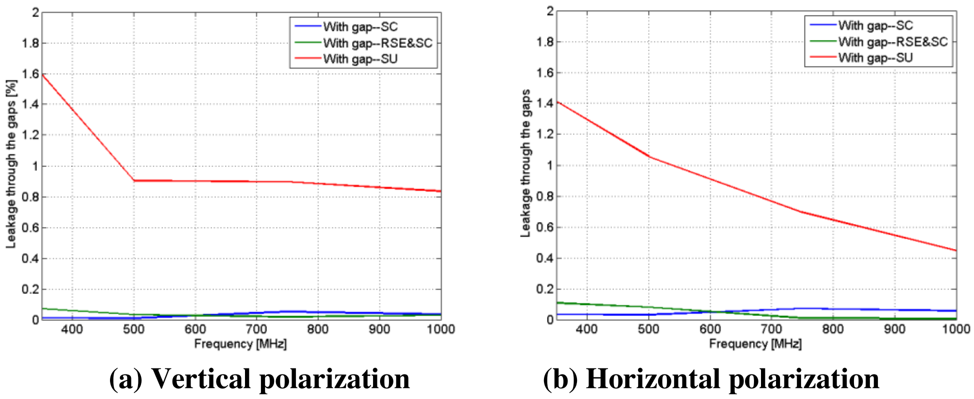


Figure 271: Ratio of the scattering energy behind the sub-reflector to full energy

As is shown in Figure 271, the leakage through the 'side uncoated (SU)' sub-reflector increases significantly, resulting in the energy ratio of this case is ~1.5% higher than the other two cases. And for the two 'side-coated (SC)' case, the maximum leakage has been well controlled to below ~0.1%.

4.3.4 Maintain Pointing

4.3.4.1 Pointing Accuracy Performance

The Pointing Accuracy Performance is predicted and managed by means of a pointing error budget. A summary of the predicted pointing performance is stated in Table 41, Table 42 and Table 43. Refer to the appendix in chapter 6.2 for further detail information on the budget.

The results indicate that the requirements are fully satisfied for the Precision Operating Conditions. However, the requirements for Relative Pointing and Tracking Stability are not fully satisfied under the Standard and Degraded Operating Conditions.

Note that the requirements were validated at the start of the Detail Design phase together with the SKAO for the Precision Operating Conditions only since this was defined as the concept and cost driving conditions. The values for the more severe conditions were determined by simply applying a factor square of the average wind speed. However the performance is dominated by the dynamic wind load, thus it would have been more valid to use scaling factor for the dynamic wind, which are different as shown in Table 44. Furthermore, it should also be noted that the budget applies worst case conditions and combinations of load cases for these predictions.

The following schematic shows how the pointing corrections will be applied.
The pointing corrections is differentiated between a classical static pointing model and a dynamic pointing corretion based on metrology sensor inputs from a Tiltmeter (located above the Az bearing in the Turnhead) and ambient sensors around the Pedestal.

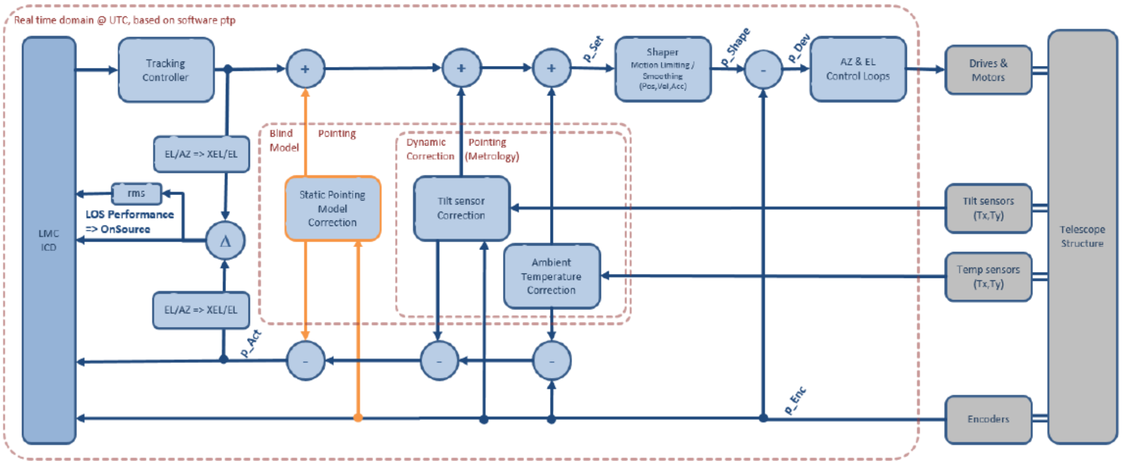


Table 41: Predicted Pointing Performance - Precision Operating Conditions

		Precision Operating Conditions (5m/s)	
		95% error circle	rms
Blind Pointing Error Circle (arcsec)	Requirement	36.0	9.0
	Budget	**14.6**	**5.5**
Relative Pointing Error Circle (arcsec)	Requirement	6.5	1.3
	Budget	**5.0**	**1.2**
Tracking Stability (arcsec)	Requirement	9.0	2.3
	Budget	**6.7**	**1.5**

Table 42: Predicted Pointing Performance - Standard Operating Conditions

		Standard Operating Conditions (7m/s)	
		95% error circle	rms
Blind Pointing Error Circle (arcsec)	Requirement	70.6	17.6
	Budget	**28.4**	**11.0**
Relative Pointing Error Circle (arcsec)	Requirement	12.7	2.5
	Budget	**17.2**	**3.5**
Tracking Stability (arcsec)	Requirement	17.6	4.5
	Budget	**23.3**	**4.4**

Table 43: Predicted Pointing Performance - Degraded Operating Conditions

		Degraded Operating Conditions (10m/s)	
		95% error circle	rms
Blind Pointing Error Circle (arcsec)	Requirement	144.0	36.0
	Budget	**52.6**	**21.7**
Relative Pointing Error Circle (arcsec)	Requirement	26.0	5.2
	Budget	**32.3**	**6.7**
Tracking Stability (arcsec)	Requirement	36.0	9.2
	Budget	**40.5**	**8.0**

Table 44: Scaling Based on Wind Speed

	POC	DOC	SOC
Stat Wind Speed (average)	5	7	10
Scale factor (used)	1.0	2.0	4.0
Dyn Wind Speed (rms)	0.68	1.24	1.53
Scale factor	1.0	3.3	5.1

4.3.5 Uncompensated (Raw) Pointing Efficiency

4.3.5.1 Raw Pointing due to Wind Load Cases

The table below shows raw uncompensated values. All 25 wind load cases are considered @ a wind speed of 2.7m/s as a static wind load calculation done by FE analysis.
The reported pointing errors are peak of both azimuth and elevation and combined as vector sum.
The table is an extract of information used in the overall error budget calculation described in 6.2.

Table 45: Pointing Accuracy due to wind @ 2.7m/s

Elevation	Azimuth	PE	PEX	Pointing
15°	0°	3.01´´	-0.01´´	3.01´´
	45°	3.20´´	-0.15´´	3.21´´
	90°	0.07´´	-0.06´´	0.09´´
	135°	1.56´´	-0.13´´	1.57´´
	180°	-1.45´´	0.04´´	1.45´´
30°	0°	0.00´´	0.00´´	0.00´´
	45°	0.00´´	0.00´´	0.00´´
	90°	0.00´´	0.00´´	0.00´´
	135°	0.00´´	0.00´´	0.00´´
45°	0°	0.09´´	-0.01´´	0.09´´
	45°	0.18´´	-0.17´´	0.18´´
	90°	0.10´´	0.17´´	0.10´´
	135°	0.75´´	-0.12´´	0.75´´
	180°	0.32´´	0.05´´	0.32´´
60°	0°	0.00´´	0.00´´	0.00´´
	45°	0.00´´	0.00´´	0.00´´
	90°	0.00´´	0.00´´	0.00´´
	135°	0.00´´	0.00´´	0.00´´
	180°	0.00´´	0.00´´	0.00´´
90°	0°	-1.85´´	-0.53´´	1.85´´
	45°	-1.53´´	0.21´´	1.53´´
	90°	0.12´´	0.52´´	0.12´´
	135°	-0.32´´	-0.04´´	0.32´´
	180°	0.93´´	-0.31´´	0.93´´

4.3.5.2 Gravity

Pointing due to gravity is a repeatable error and reduced to a negligible small value by means of look-up-tables.

4.3.5.3 Raw Pointing due to Thermal Load Cases

Table 46: Pointing Accuracy due to Thermal Load Cases

	Load Case	Pointing [arcsec]
1	Ambient Temperature Change by 20 K	0.8
2	Gradient 3 K along x axis	1.0
3	Gradient 4 K along y axis	1.3
4	Gradient 1 K along z axis	0.3

4.3.6 Dynamic Analysis

4.3.6.1 Introduction

The dynamic analysis in this report is performed in the frequency and time domains using the 'Matlab Control Toolbox' and based on the Finite-Element-Model (FEM) of the structure. FEM is converted into a state-space representation in Matlab for 3 representative elevation angles (15^0 , 45^0 and 90^0). Details can be found below.
The motion values relevant for the dynamic analyses for both axes are given in the table below.

Table 47: Maximum Velocity and Acceleration

Azimuth	Elevation
$v_{max,slew} = 3°/s$	$v_{max,slew} = 1°/s$
$a_{max,slew} = 2°/s^2$	$a_{max,slew} = 2°/s^2$
$v_{max,tracking} = 0.3°/s$	$v_{max,tracking} = 0.08°/s$

4.3.6.2 Model Overview

The analysis in this report is performed in the frequency and time domains using the Matlab Control Toolbox based on the Finite-Element-Model (FEM) of the structure. FEM is converted into a state-space representation in Matlab. It serves as a starting point for controller tuning resulting in the system closed loop model. The close loop model is finally used to verify the performance requirements.
Two FEMs are used to model the telescope behaviour:

- with the tipping structure at 15-degrees elevation angle (EL15)
- with the tipping structure at 45-degrees elevation angle (EL45)
- with the tipping structure at 90-degrees elevation angle (EL90)

The mechanical parts of the motor model: the moments of inertia and the stiffness of the drive train are included in the FEM.

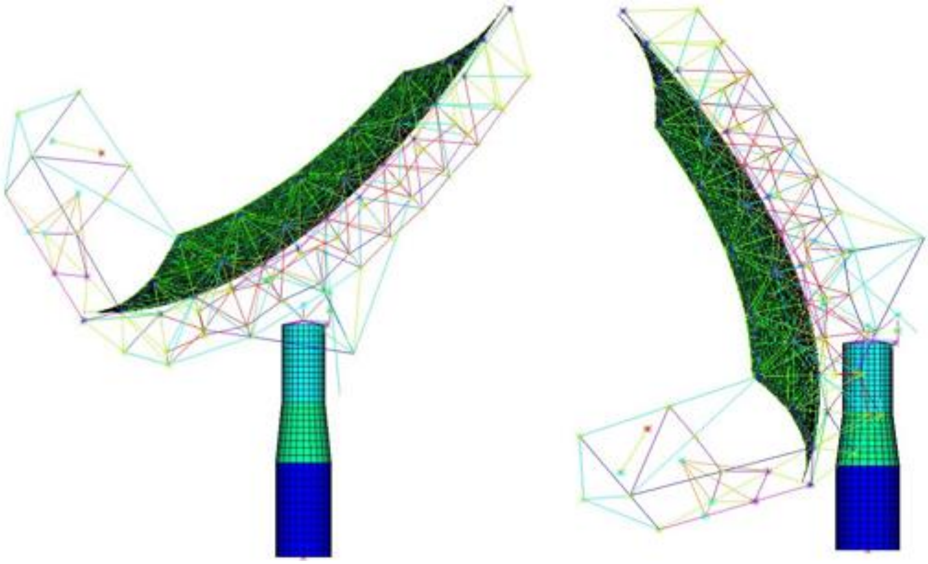


Figure 272: Two Example Positions of the Mount Structure Used for Simulation

The following optimization steps have been taken to generate a reduced FEM used for a state-space representation in Matlab:

- a number of nodes relevant for the dynamic model have been selected for the analysis (input and outputs)
- in order to ensure effective modelling of system dynamics and at the same time to keep the number of eigenfrequencies to minimum, so-called balanced model reduction has been performed to the original FEM in ANSYS

To simulate dynamic response under different loads a state-space model of the mechanical structure is derived from the FEM in the form

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

The state-space representation is obtained from the vector of eigenfrequencies and the eigenmodes-matrix using modal coordinates. The matrices of the state-space form are:

$$A = \begin{bmatrix} \underline{0} & \underline{I} \\ -\Omega^2 & -2Z\Omega \end{bmatrix}$$

$$B = \begin{bmatrix} \underline{0} \\ \Phi^T F \end{bmatrix}$$

$$C = \begin{bmatrix} C_{op}\Phi & C_{ov}\Phi \end{bmatrix}$$

$$D = [\underline{0}]$$

C_{op}, C_{ov} – position and velocity output matrices

where Ω - is the diagonal matrix of eigenfrequencies

Z- is the diagonal modal damping matrix

Φ- is the matrix of eigenvectors

F- is the input matrix

The damping values are assumed independent on frequency and all set to 2%, which is known as a reasonable estimation for steel structures.

4.3.6.3 Controller

An overview of the controller architecture is given below. The azimuth and elevation axes are controlled separately. The wind forces (parameterized by wind pressure at M1 and M2) are represented by the disturbance input. The controller consists of a command shaper (TG), two feedforward blocks and two cascaded feedback loops. Outputs of the structural model are simulated readouts of the axis encoder and motor tachometers, as well as pointing errors. Inputs are motor torques and disturbances represented by wind pressures on the primary and the secondary.

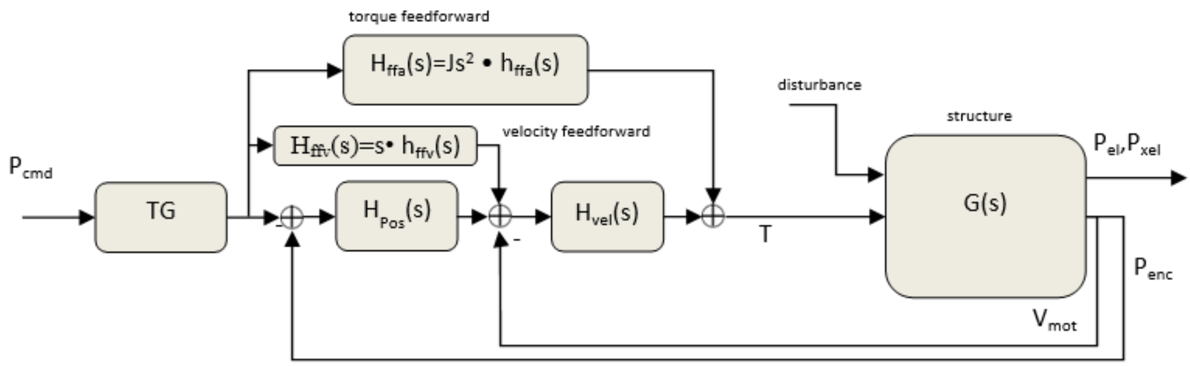


Figure 273: Architecture of the Axis Controller

A command shaper used in the proprietary MTM control system is called Trajectory Generator (TG). The main goal of the trajectory generator is to generate a modified command, close to the original making sure that the velocity and the acceleration are within the specified limits. This is achieved by using nearly sine-shaped (or linear-shaped) ace-/deceleration trajectories under consideration of demanded position and/or velocity command. The software package of the MTM control system utilizes sophisticated algorithms that cannot be represented by a simple formula. A scripted version of the trajectory generator derived from the actual control software has been used to generate test trajectories for settling time evaluation.

The first loop in the feedback cascade hierarchy is the velocity loop. Inputs to the velocity loop are the positions loop outputs and the tachometer signals of servo drives. The tachometer signals are used to ensure a collocated response due to stability reasons. The velocity loop compensator H_{vel} is implemented as a standard PI-controller $H_{PI} = K_p s + K_i$ although can be easily extended to a PID-type that is the case in the MTM control system software.
The parameters of a PI compensator can be initially guessed based on a rigid-body analysis assuming a PI control with well-damped poles of the closed loop transfer function:

$$\Theta s^2 + K_p s + K_i = \Theta(s^2 + 2\xi_v \omega_v s + \omega_v^2),$$

where Θ is moment of inertia of the axis, $\xi_v = \frac{\sqrt{3}}{2}$ is a damping factor corresponding to a 60 deg phase margin, $\omega_v = 2\pi f_v = 2\pi f_{cv}/2$, and f_{cv} is expected bandwidth for the rigid-body closed velocity loop and the only free parameter to tune:

$$K_i = \Theta\omega_k^2\,, \qquad K_p = 2\Theta\xi_k\omega_k$$

The position loop keeps a telescope axis in the desired inertial angular position and uses position feedback from the encoder. The velocity loop compensator H_{pos} is implemented as a standard P-controller$H_P = K_p$althoughit can be easily extended to a PI-type controller. The proportional gain of the position loop can likewise be initially guessed by means of the rigid-body assumption where the internal velocity loop is considered as having idealized a unit transfer function:

$$K_p = \omega_p$$

where $\omega_p = 2\pi f_p = 2\pi f_{cp}/2$ andf_{cp} is expected bandwidth for the rigid-body closed velocity loop and the only free parameter to tune.

The primary goal of the acceleration feedforward block is to boost the servo performance at low frequencies. It takes its input from the acceleration output of the command shaper, scales it with moment of inertia $\theta$of the corresponding telescope axis and applies an additional low path filter $h_{ffa}(s)$:

$$H_{ffa}(s) = \theta s^2 h_{ffa}(s)$$

The output of the feedforward serves as an additional input to the torque command.
The velocity feedforward plays for the position loop the same role as the acceleration feedforward for the velocity loop: theoretically, in the absence of disturbances and for "slow" input trajectories, the feedforward part of the controller should be able to assure "an ideal" tracking behaviour. In reality, a properly tuned feedforward block relieves the feedback compensator during acceleration/deceleration phases.

$$H_{ffv}(s) = s h_{ffv}(s)$$

Feedforward controllers is known as improving tracking accuracy at high velocities. However, the disturbance transfer function is not affected and the disturbance rejection properties are not improving.

4.3.6.4 Transfer Functions

Characteristics of control loops are presented in this section. When considering controller performance the state space model of the structure is extended by a time delay block. This is to account for a processing delay of the whole servo loop, which was experimentally measured to be ~7 msec.

4.3.6.4.1 Azimuth Axis

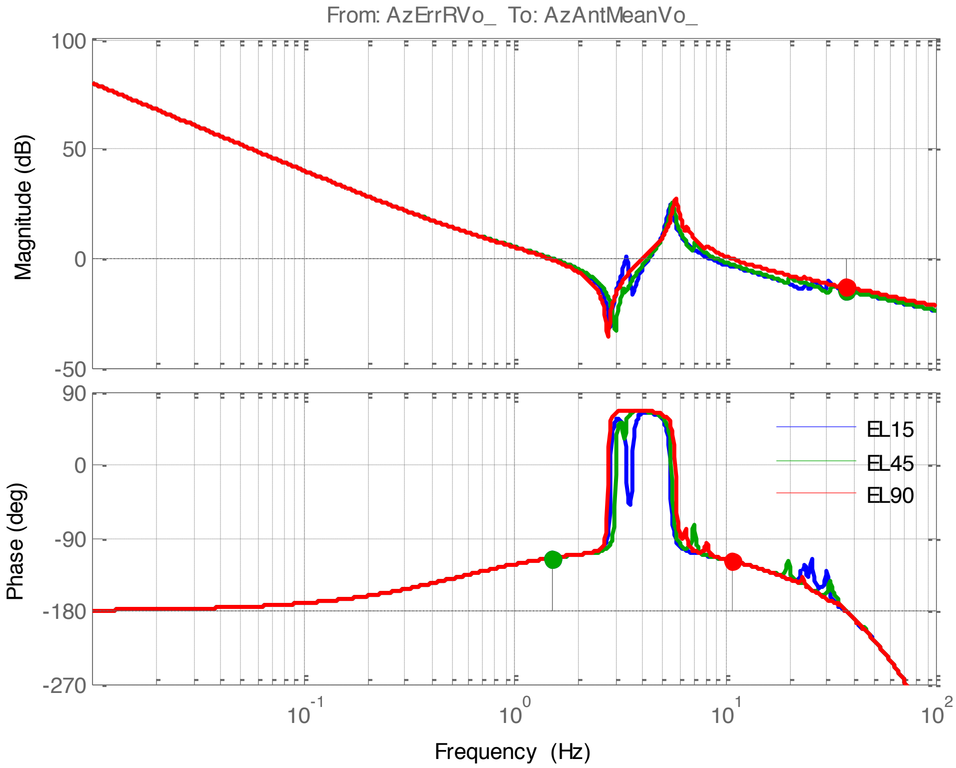


Figure 274: Open Velocity Loop Frequency Responses for Azimuth

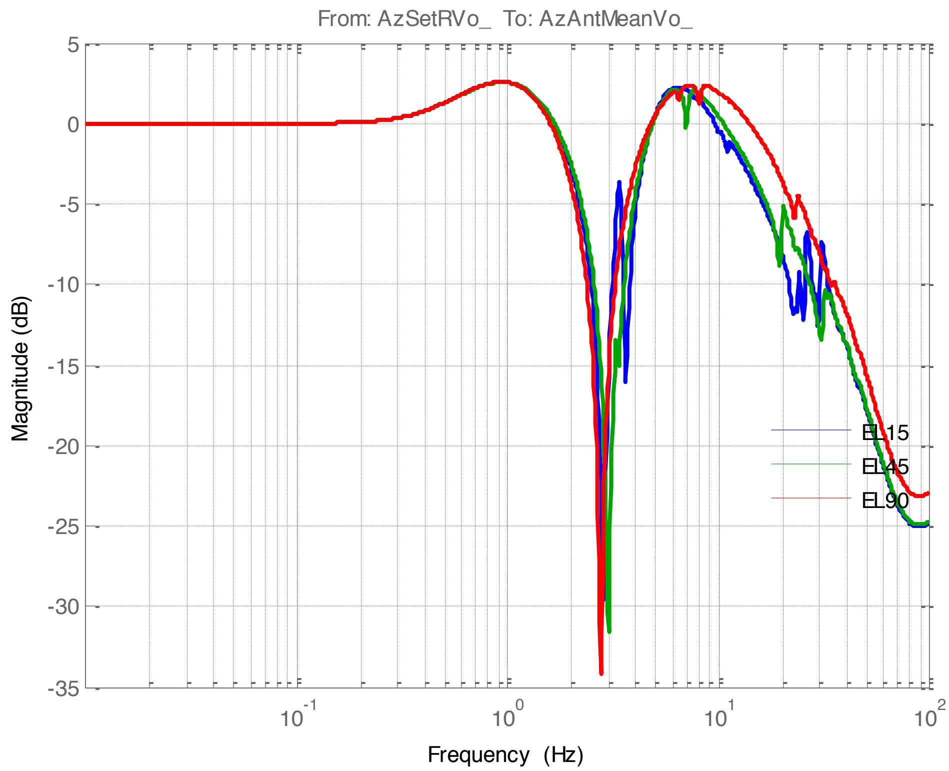


Figure 275: Closed Velocity Loop Frequency Responses for Azimuth

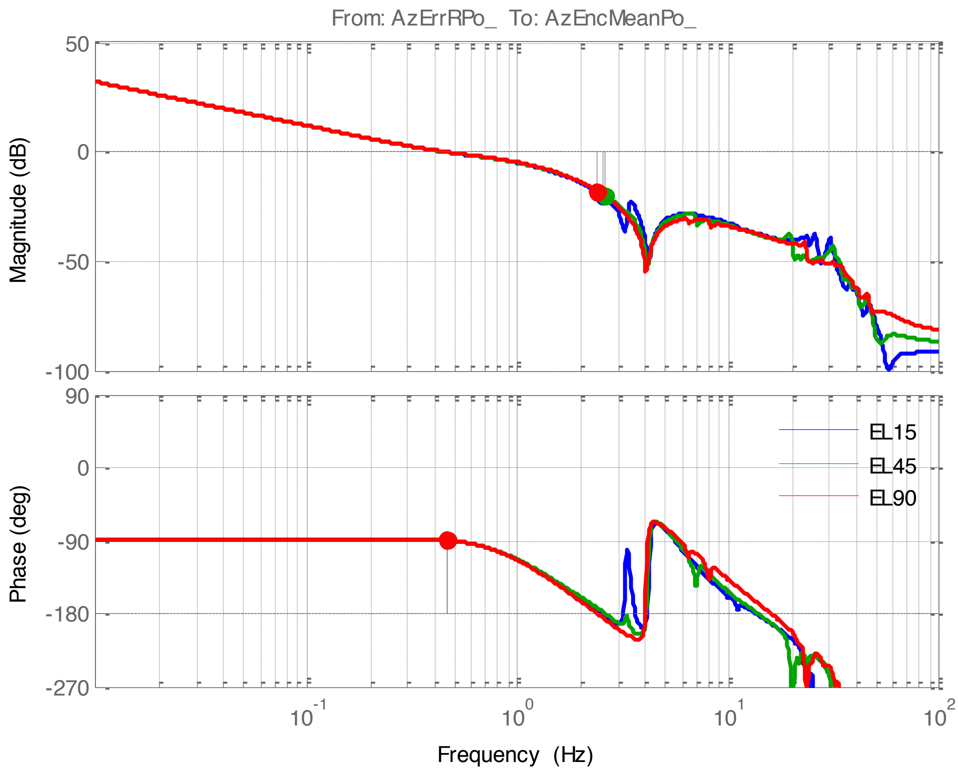


Figure 276: Open Position Loop Frequency Responses for Azimuth

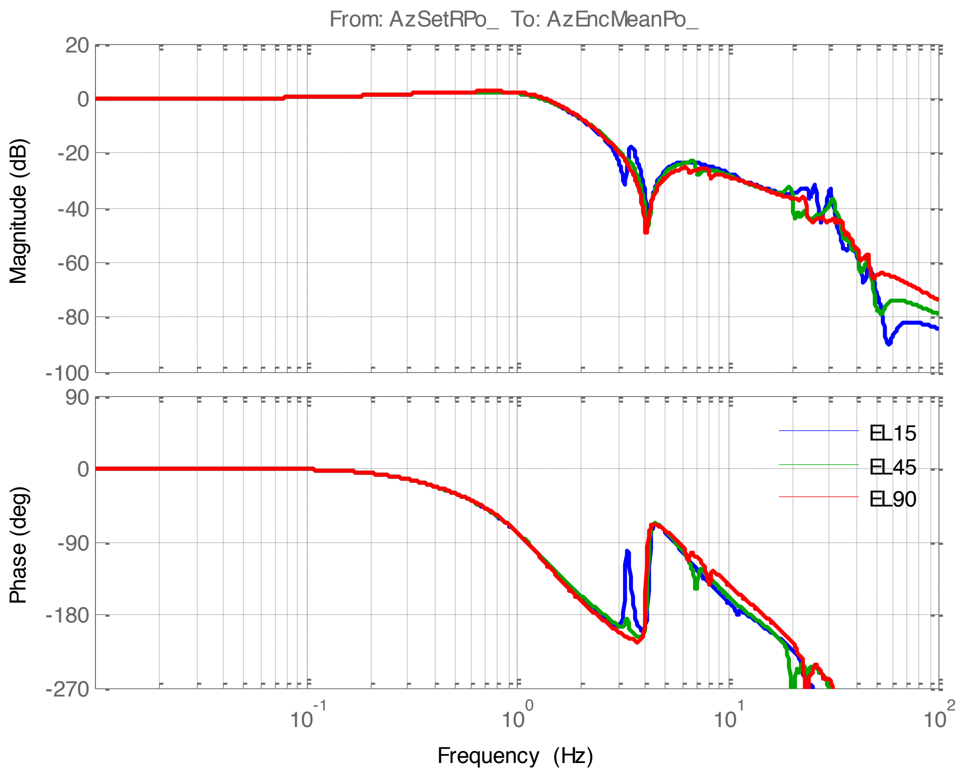


Figure 277: Closed Position Loop Frequency Responses for Azimuth

Table 48: Control Loop Performance for the Azimuth Axis

		EL15	EL45	EL90
Velocity Loop	Phase Margin	65 deg	61 deg	62 deg
	Gain Margin	15 dB	14 dB	13 dB
	Bandwidth	2.0 Hz	2.0 Hz	1.9
Position Loop	Phase Margin	90 deg	90 deg	90 deg
	Gain Margin	20 dB	20 dB	18 dB
	Bandwidth	1.6 Hz	1.6 Hz	1.6 Hz

4.3.6.4.2 Elevation Axis

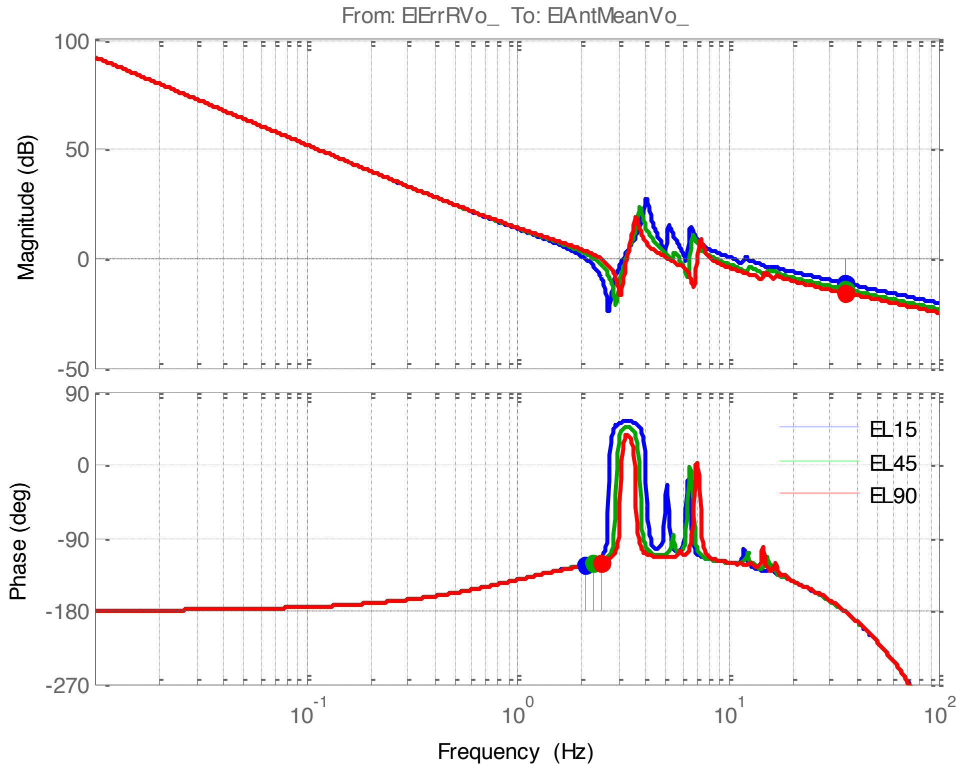


Figure 278: Open Velocity Loop Frequency Responses for Elevation

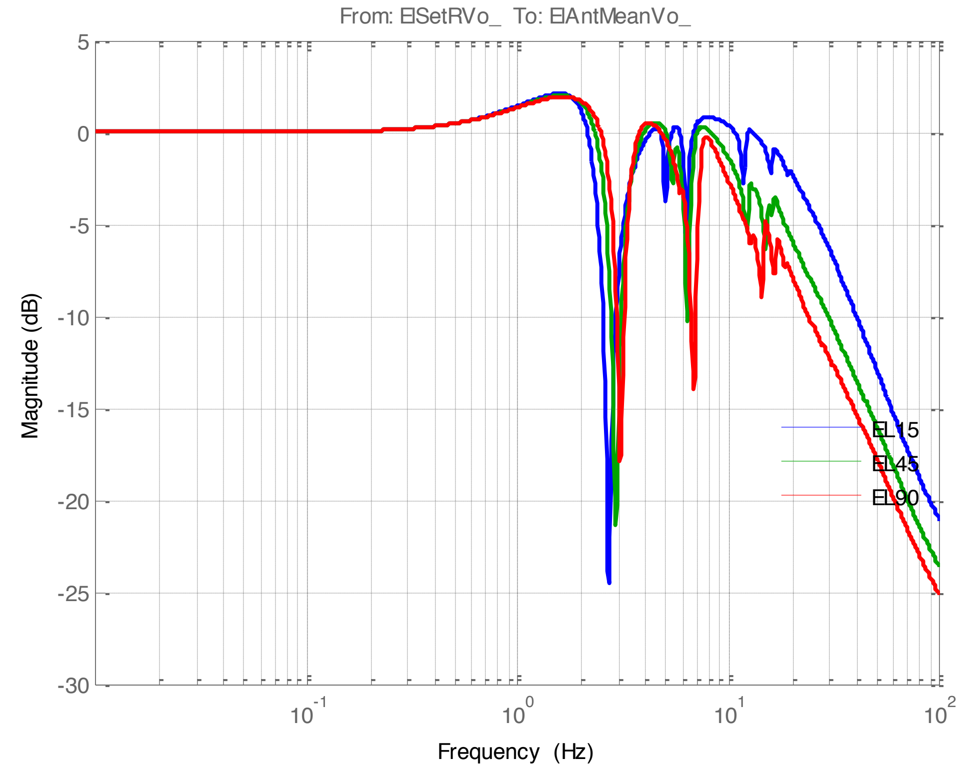


Figure 279: Closed Velocity Loop Frequency Responses for Elevation

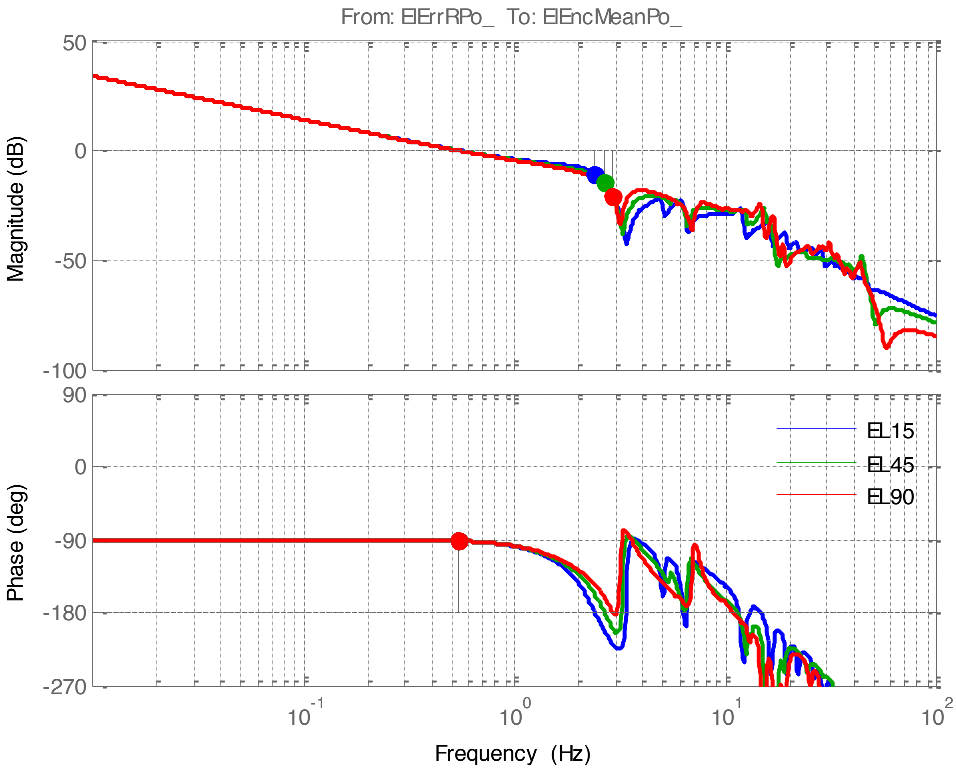


Figure 280: Open Position Loop Frequency Responses for Elevation

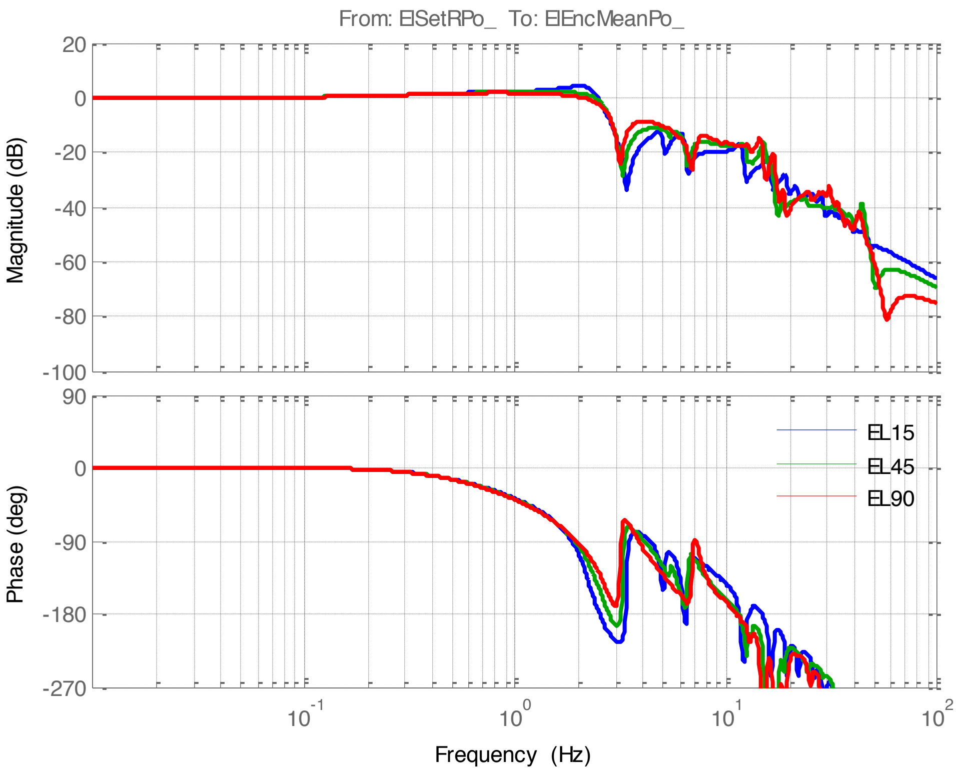


Figure 281: Closed Position Loop Frequency Responses for the Elevation Axis

Table 49: Control Loop Performance for the Elevation Axis

		EL15	EL45	EL90
Velocity Loop	Phase Margin	57 deg	59 deg	60 deg
	Gain Margin	11 dB	14 dB	15 dB
	Bandwidth	2.3 Hz	2.5 Hz	2.7
Position Loop	Phase Margin	88 deg	88 deg	88 deg
	Gain Margin	10 dB	14 dB	21 dB
	Bandwidth	2.5 Hz	2.5 Hz	2.5 Hz

4.3.6.5 Dynamic Wind Analysis

4.3.6.5.1 Input Data

The wind dynamic analysis is limited to the wind gust disturbances and dynamical responses and does not include structural responses caused by an idealized static wind forces.

Three wind jitter scenarios are considered which correspond to three specified wind categories:

- Precision (u_{mean} <= 5m/s)
- Standard (5m/s $< u_{mean}$ <=7m/s)
- Degraded (7m/s $< u_{mean}$ <=10m/s)

The normalised data for 10 m above the ground has been analysed and show that these categories has following characteristics:

Table 50: Wind speed characteristics for different categories

	Precision	Standard	Degraded
u_{mean}	2.7 m/s	5.93 m/s	8.07 m/s
u_{rms}	0.68 m/s	1.24 m/s	1.53 m/s
Rescaled: u_{rms}	1.27 m/s	1.46 m/s	1.89 m/s

The last row represents the RMS values rescaled to the corresponding maximum mean speed values. E.g. for the Precision Category: u_{rms} (rescaled) = u_{rms}/u_{mean}*5=0.68/2.7*5=1.27

4.3.6.5.2 Model Setup

The dynamic analysis is limited to the wind-gust disturbances and dynamical responses and does not include structural responses caused by an idealized static wind forces. Four main calculations steps are shown in the diagram below

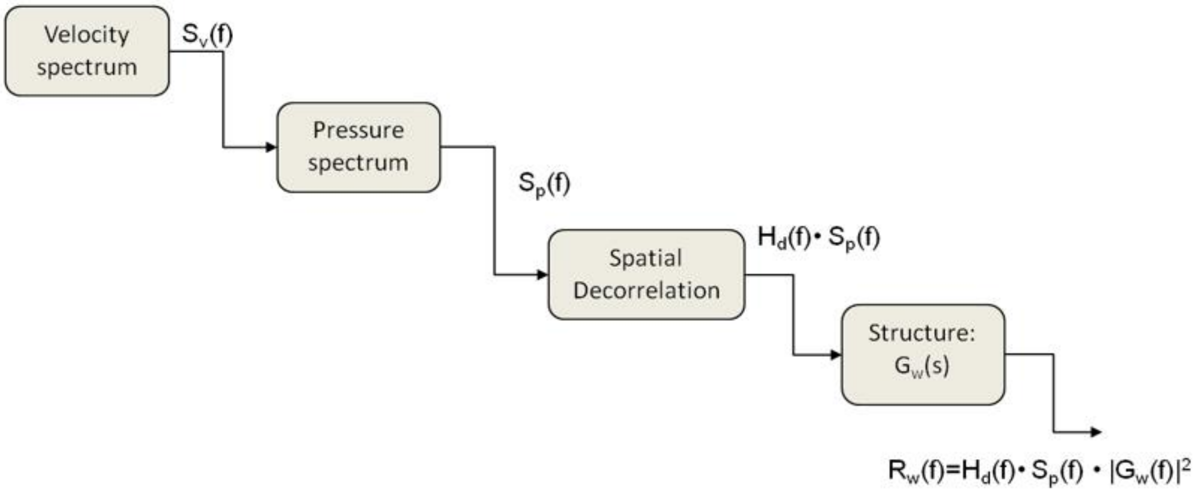


Figure 282: Main Steps of the Dynamic Wind Analysis

4.3.6.5.3 Wind Speed

The normalised data for 10 m above the ground has been analysed with the goal to find out the onsite spectrum. Empirical form of the onsite spectrum turned out to be:

$$\frac{S_v(f)}{u_{rms}^2} = \frac{a}{f(bf+1)}$$

where a and b are fixed parameters.

The parameters has been identified based on data as shown in the following table:

Table 51: Parameters for the Wind Speed Spectra

	Precision	Standard	Degraded
a	0.275	0.275	0.241
b	10	10	5

The comparison of the measured and approximated normalised spectra is shown below:

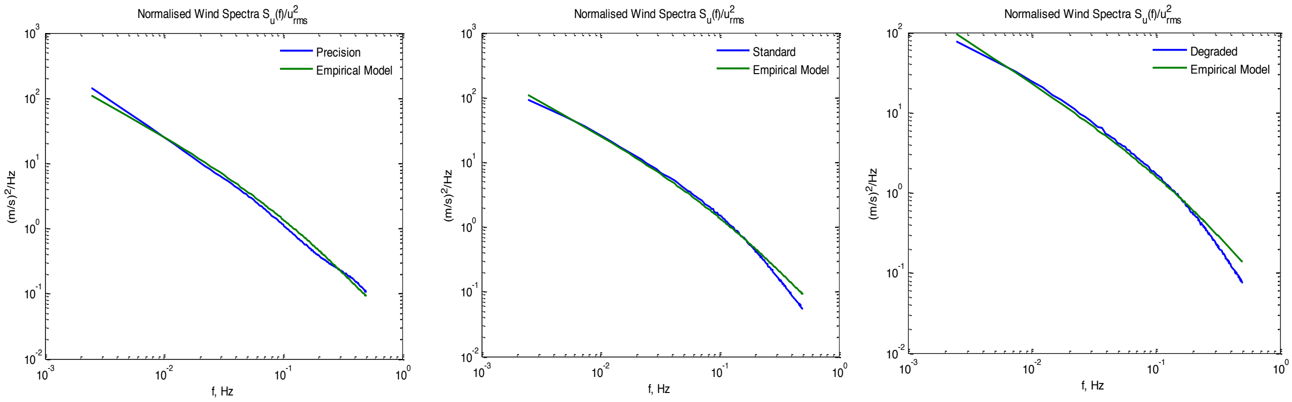


Figure 283: Normalised Wind Spectra for 3 Categories: Empirical vs. Measured

4.3.6.5.4 Wind Pressure

The mean pressure is calculated based on the mean speed:

$$p_{mean} = 0.5\rho u_{mean}^2$$

where ρ is the air density (assumed 1.2 kg/m³). The RMS unsteady pressure p_{rms} can be expressed by the following equations:

$$p_{rms} = 0.5\rho u_{eff}^2$$

$$u_{eff}^4 = (2u_{mean}u_{rms})^2 + 2u_{rms}^4$$

where u_{eff} is known as the effective speed and u_{rms} is the wind speed RMS. It is easy to see that even for relatively high u_{rms} values the second term can be neglected and a simplified formula for the RMS pressure becomes:

$$p_{rms} = \rho u_{mean}u_{rms}$$

In this case, the pressure spectrum has nearly the same form as the input wind speed spectrum:

$$S_p(f) = (\rho u_{mean})^2 S_v(f)$$

The wind force is obtained by integrating pressure over a surface of area. At low frequencies, the unsteady pressure is spatially correlated over long distances, while at higher frequencies the spatial correlation length decreases. This effect can be considered in the frequency domain by using a weighting function called spatial decorrelation or aerodynamic attenuation, which value is 1 at zero-frequency and having damping effect at higher frequencies:

$$S_F(f) = (A\,C_D)^2 H_d(f) S_P(f)$$

where $S_F(f)$ - force spectrum
$H_d(f)$ - spatial decorrelation factor
A - area of attack
C_D – drag coefficient

In the current model, the drag coefficients C_D, as well as the areas of attack for the primary and the secondary are integrated into the FEM. Therefore, the force spectrum is not calculated explicitly and the pressure spectrum is applied as the pressure input to the state-space representation in Matlab. The spatial decorrelation factor $H_d(f)$ is currently set to 1 which is a conservative assumption.

4.3.6.5.5 Wind Jitter Simulation Results

In this section, detailed results of dynamic wind analysis are given for 3 elevation angels EL15, EL45 and EL90 and 3 wind categories (time frame 100 s).
Calculations are performed for overall 5 directions of wind [AZ0 AZ45 AZ90 AZ135 AZ180] starting with AZ0 which means that the wind is blowing directly into the primary.

Table 52: Dynamic Wind Results for the Precision Conditions

Precision conditions						
Pointing Error due to dynamic wind						
Elevatio	Azimuth	Distribution		Cross-Elevation	Elevation	Pointing
15°	0°	1	1	0.00´´ rms	0.81´´ rms	0.81´´ rms
	45°		1	0.08´´ rms	0.85´´ rms	0.85´´ rms
	90°		1	0.63´´ rms	0.07´´ rms	0.63´´ rms
	135°		1	0.66´´ rms	0.10´´ rms	0.67´´ rms
	180°		1	0.02´´ rms	0.60´´ rms	0.60´´ rms
RMS				0.41´´ rms	0.59´´ rms	0.71´´ rms
45°	0°	1	1	0.00´´ rms	0.77´´ rms	0.77´´ rms
	45°		1	0.06´´ rms	0.87´´ rms	0.87´´ rms
	90°		1	0.58´´ rms	0.06´´ rms	0.58´´ rms
	135°		1	0.62´´ rms	0.13´´ rms	0.64´´ rms
	180°		1	0.02´´ rms	0.67´´ rms	0.67´´ rms
RMS				0.38´´ rms	0.60´´ rms	0.71´´ rms
90°	0°	1	1	0.01´´ rms	0.79´´ rms	0.79´´ rms
	45°		1	0.22´´ rms	0.68´´ rms	0.72´´ rms
	90°		1	0.44´´ rms	0.08´´ rms	0.44´´ rms
	135°		1	0.40´´ rms	0.36´´ rms	0.54´´ rms
	180°		1	0.01´´ rms	0.72´´ rms	0.72´´ rms
RMS				0.28´´ rms	0.59´´ rms	0.64´´ rms
		Minimum		0.00´´ min rms	-0.06´´ min rms	-0.44´´ min rms
		Maximum		0.66´´ max rms	0.87´´ max rms	0.87´´ max rms
		Mean		0.25´´ min rms	0.28´´ min rms	0.73´´ min rms
		RMS		0.36´´ rms	0.59´´ rms	0.70´´ rms

Table 53: Dynamic Wind Results for the Standard Conditions

Standard conditions						
Pointing Error due to dynamic wind						
Elevatio	Azimuth	Distribution		Cross-Elevation	Elevation	Pointing
15°	0°	1	1	0.00´´ rms	3.84´´ rms	3.84´´ rms
	45°		1	0.41´´ rms	4.02´´ rms	4.04´´ rms
	90°		1	3.10´´ rms	0.36´´ rms	3.12´´ rms
	135°		1	3.20´´ rms	0.58´´ rms	3.25´´ rms
	180°		1	0.07´´ rms	2.80´´ rms	2.80´´ rms
	RMS			2.00´´ rms	2.80´´ rms	3.44´´ rms
45°	0°	1	1	0.02´´ rms	3.56´´ rms	3.56´´ rms
	45°		1	0.27´´ rms	4.01´´ rms	4.02´´ rms
	90°		1	2.75´´ rms	0.32´´ rms	2.77´´ rms
	135°		1	2.93´´ rms	0.69´´ rms	3.01´´ rms
	180°		1	0.10´´ rms	3.04´´ rms	3.04´´ rms
	RMS			1.80´´ rms	2.78´´ rms	3.31´´ rms
90°	0°	1	1	0.03´´ rms	3.54´´ rms	3.54´´ rms
	45°		1	0.97´´ rms	3.00´´ rms	3.15´´ rms
	90°		1	1.86´´ rms	0.38´´ rms	1.90´´ rms
	135°		1	1.68´´ rms	1.60´´ rms	2.32´´ rms
	180°		1	0.06´´ rms	3.12´´ rms	3.12´´ rms
	RMS			1.20´´ rms	2.61´´ rms	2.87´´ rms
		Minimum		0.00´´ min rms	-0.32´´ min rms	-1.90´´ min rms
		Maximum		3.20´´ max rms	4.02´´ max rms	4.04´´ max rms
		Mean		1.16´´ min rms	1.31´´ min rms	3.38´´ min rms
		RMS		1.70´´ rms	2.73´´ rms	3.22´´ rms

Table 54: Dynamic Wind Results for the Degraded Conditions

Degraded conditions						
Pointing Error due to dynamic wind						
Elevatio	Azimuth	Distribution		Cross-Elevation	Elevation	Pointing
15°	0°	1	1	0.01´´ rms	7.31´´ rms	7.31´´ rms
	45°		1	0.81´´ rms	7.64´´ rms	7.68´´ rms
	90°		1	6.10´´ rms	0.76´´ rms	6.15´´ rms
	135°		1	6.34´´ rms	1.29´´ rms	6.47´´ rms
	180°		1	0.15´´ rms	5.33´´ rms	5.33´´ rms
RMS				3.95´´ rms	5.34´´ rms	6.64´´ rms
45°	0°	1	1	0.04´´ rms	6.64´´ rms	6.64´´ rms
	45°		1	0.52´´ rms	7.46´´ rms	7.48´´ rms
	90°		1	5.32´´ rms	0.69´´ rms	5.37´´ rms
	135°		1	5.70´´ rms	1.45´´ rms	5.88´´ rms
	180°		1	0.19´´ rms	5.66´´ rms	5.66´´ rms
RMS				3.50´´ rms	5.18´´ rms	6.25´´ rms
90°	0°	1	1	0.05´´ rms	6.61´´ rms	6.61´´ rms
	45°		1	1.73´´ rms	5.50´´ rms	5.77´´ rms
	90°		1	3.33´´ rms	0.76´´ rms	3.42´´ rms
	135°		1	3.05´´ rms	3.12´´ rms	4.36´´ rms
	180°		1	0.10´´ rms	5.75´´ rms	5.75´´ rms
RMS				2.16´´ rms	4.84´´ rms	5.31´´ rms
		Minimum		-0.01´´ min rms	-0.69´´ min rms	-3.42´´ min rms
		Maximum		6.34´´ max rms	7.64´´ max rms	7.68´´ max rms
		Mean		2.23´´ min rms	2.53´´ min rms	6.34´´ min rms
		RMS		3.29´´ rms	5.13´´ rms	6.09´´ rms

For illustration, PSDs of the system responses (precision condition) are shown below:

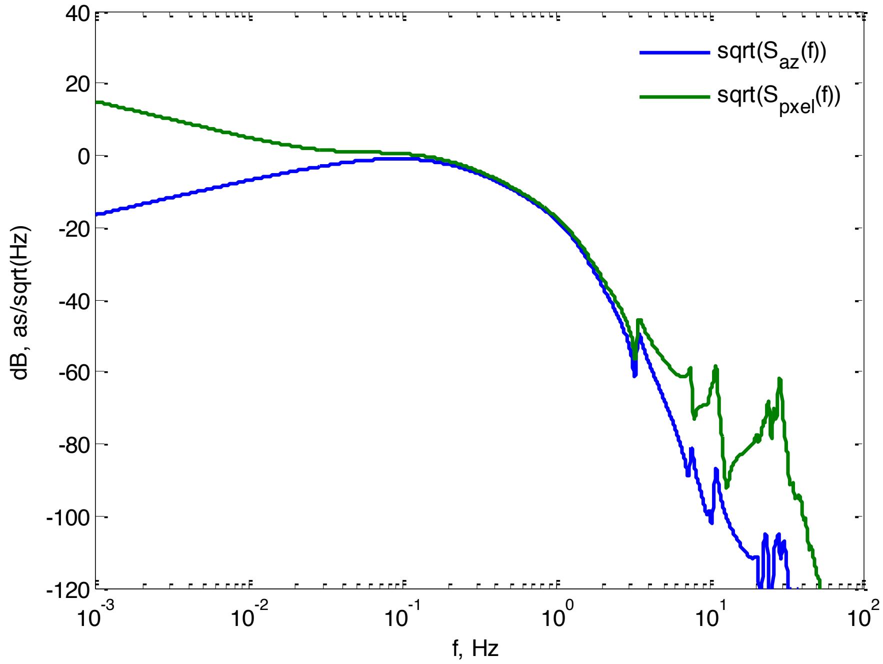


Figure 284: PSD of the Close Loop Disturbance System Response for Azimuth (AZ) and Pointing Cross-Elevation (XEL) Axes

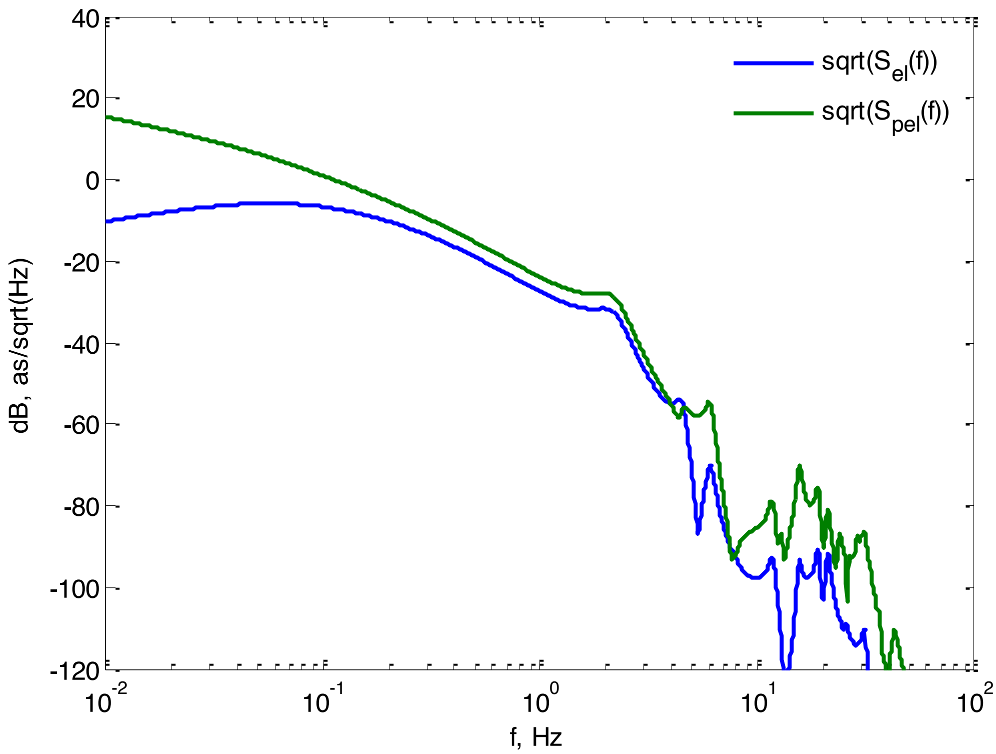


Figure 285: PSD of the Close Loop System Response for Elevation (EL) and Pointing Elevation (PEL) Axes

4.3.6.6 Use Cases

In this section, a number of use cases are described and simulation results are given.

4.3.6.6.1 Use Case A

<u>Description as Provided by SKA</u>

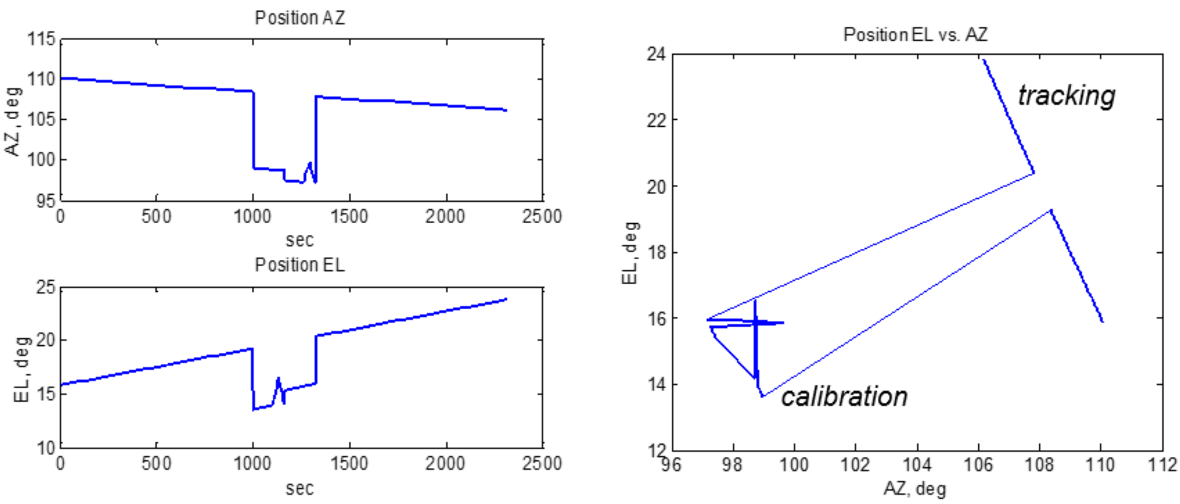
A: 12-hour Observation with Reference Pointing

- Assume the Latitude of the dish is -30 deg.
- Precision conditions (50% day; 50% night).
- Track a science field from -5.7 to 5.7 hours at a Declination of -25 deg. (North of zenith)
- Carry out the following loop:
  - Track science field: 1000 s.
  - Move to a calibration source at the same HA, at a Declination of -15 deg.
  - Note that the calibration source may go below the elevation limit at the extremes of HA.
  - Change the indexer from the most extreme position to the central position.
    - This motion can be overlapped in time with moving to the calibrator source.
  - At the calibrator position execute the following:
    - Carry out a 30-s scan across the calibrator in the S-N direction.
    - Carry out a 30-s scan across the calibrator in the E-W direction.
  - Return to the science field.
  - Repeat for 12 hours.
- Maintain pointing requirements in tracking mode for each segment.
- Report results of simulation:
  - Settling times.
  - Overall efficiency (% time on source or on calibrator).

<u>Additional Assumptions:</u>

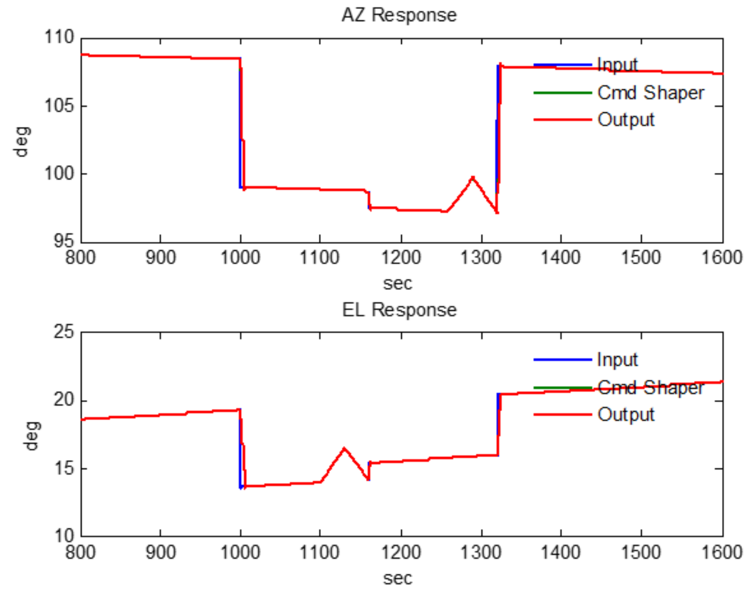
- The indexer motion is finished during slewing, scan Length = 3 x FWHM for EL and AZ

<u>Input Trajectory:</u>



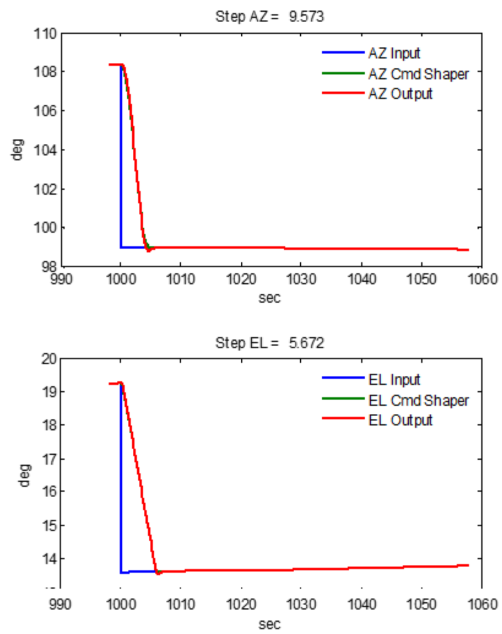
<u>Simulation Results:</u>

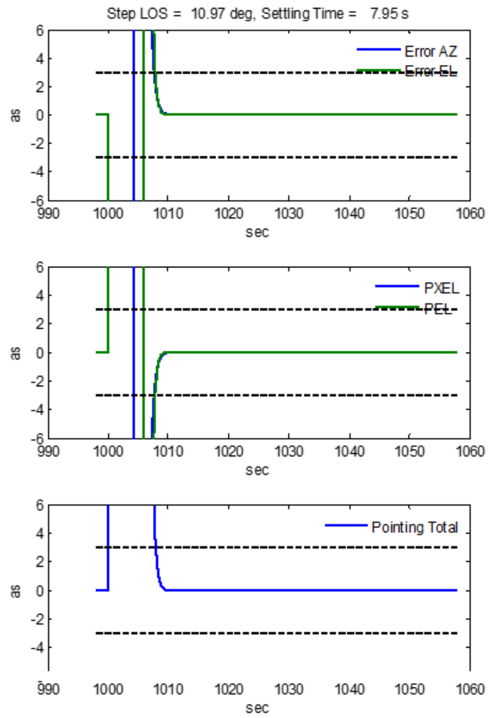
Use Case A: System Response



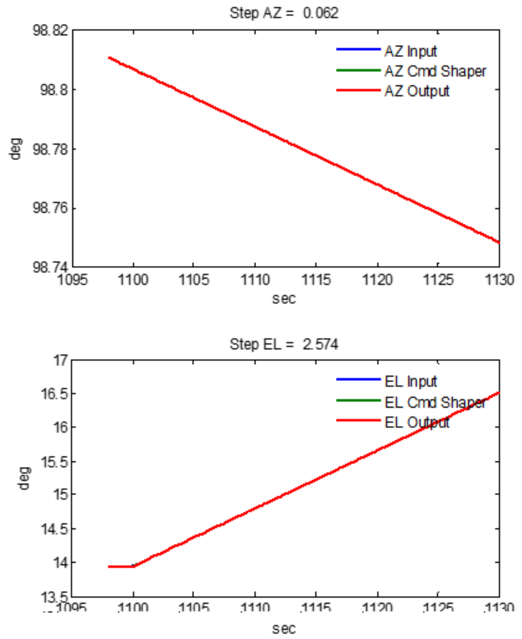
96.3 % on source
for 3 arcsec pointing error

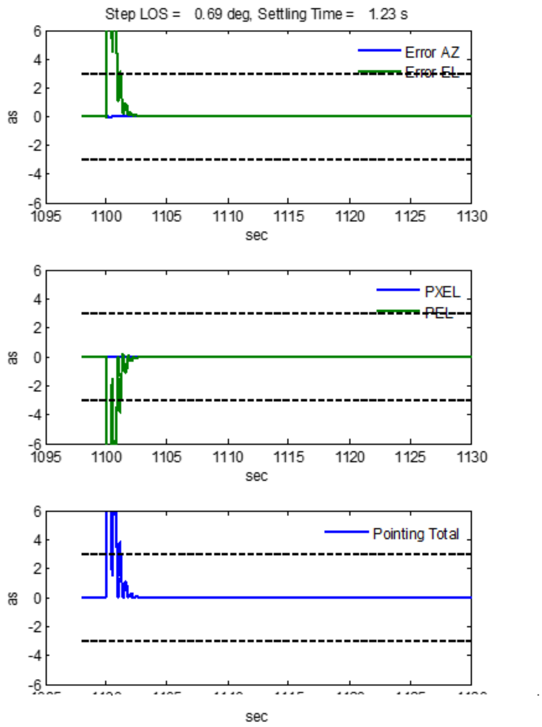
Use Case A: From Tracking to Calibration



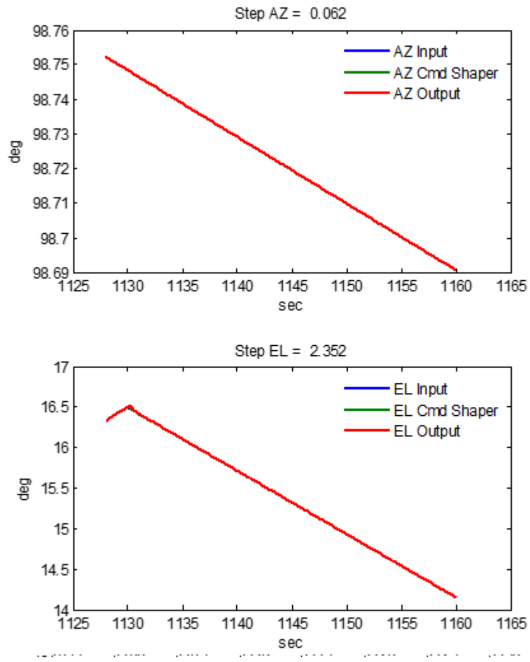


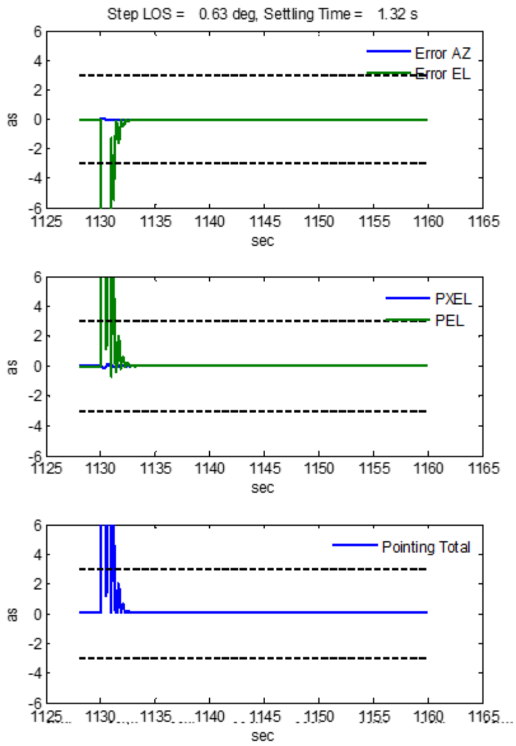
Use Case A: Calibration El↑



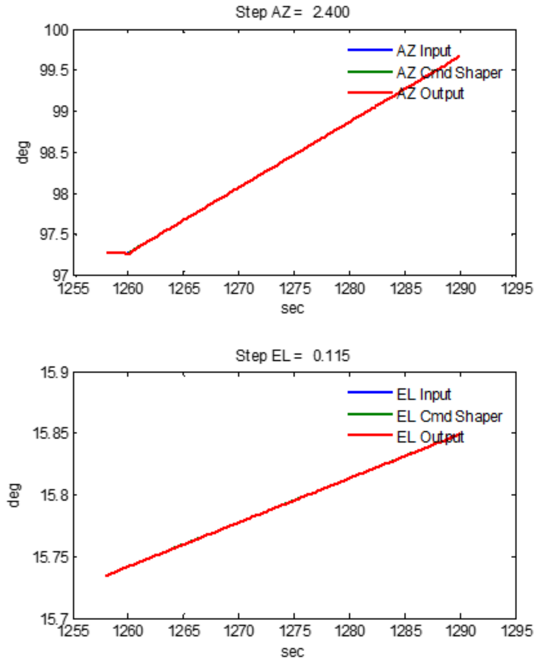


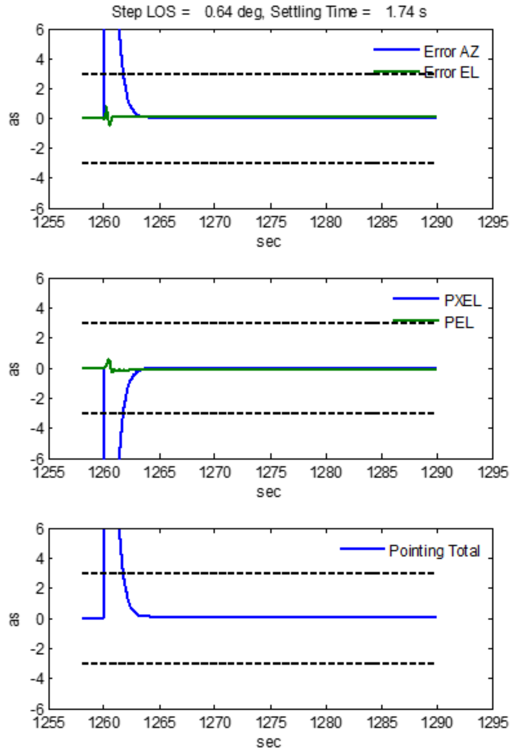
Use Case A: Calibration El↓



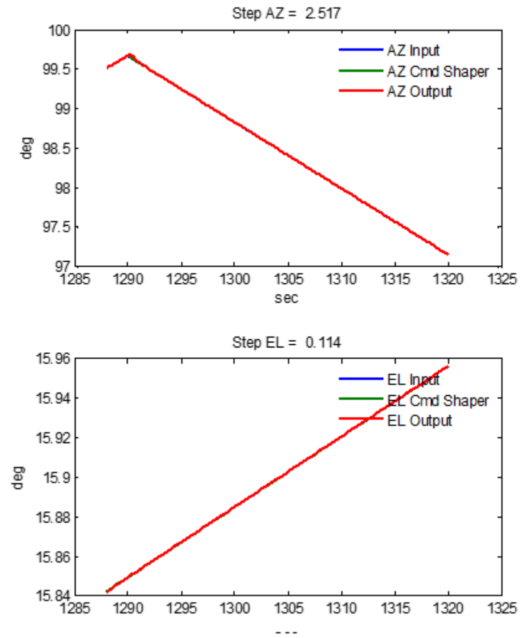


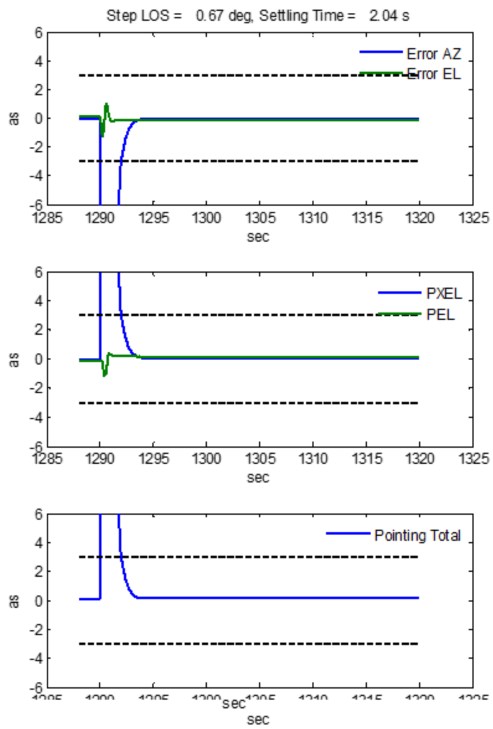
Use Case A: Calibration Az ↑

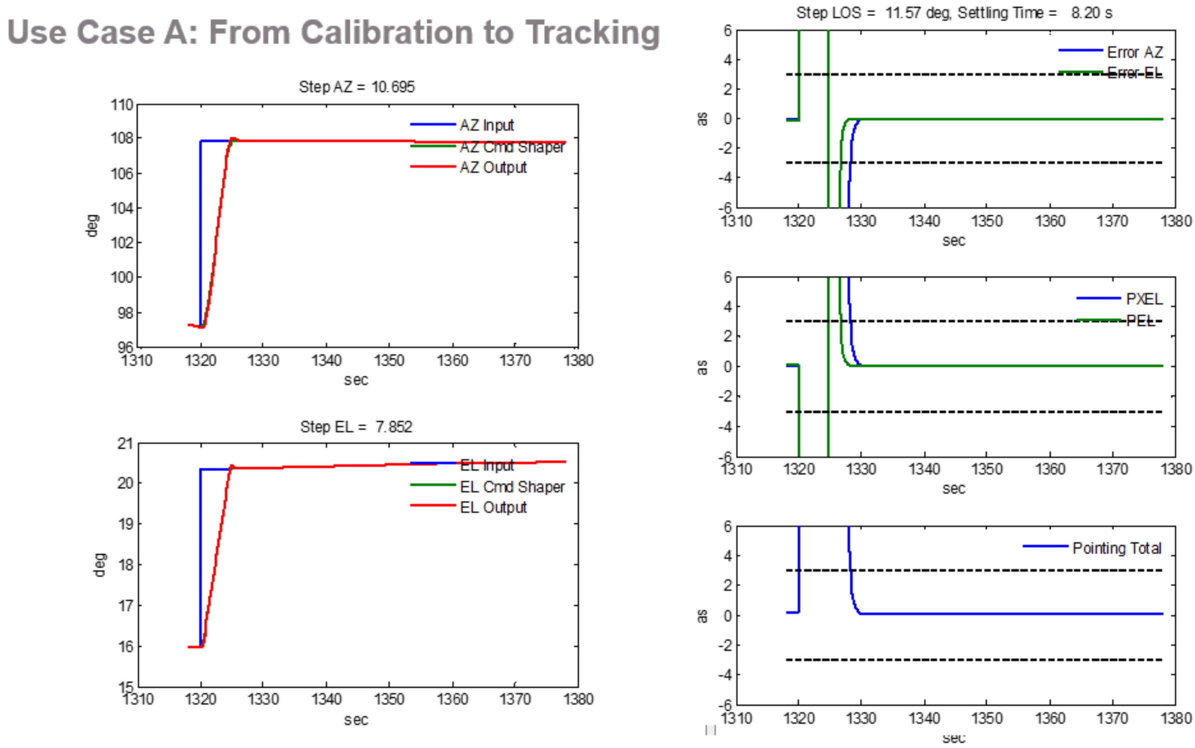




Use Case A: Calibration Az ↓







4.3.6.6.2 Use Case B

<u>Description as Provided by SKA:</u>

B: 12-hour Observation with Reference Pointing

- Assume the Latitude of the dish is -30 deg.
- Precision conditions (50% day; 50% night).
- Track a science field from -6 to 6 hours at a Declination of -35 deg. (South of zenith).
- Carry out the following loop:
  - Track science field: 1000 s.
  - Move to a calibration source at the same HA, at a Declination of -45 deg.
  - Change the indexer from the most extreme position to the central position.
    - This motion can be overlapped in time with moving to the calibrator source.
  - At the calibrator position execute the following:
    - Carry out a 30-s scan across the calibrator in the S-N direction.
    - Carry out a 30-s scan across the calibrator in the E-W direction.
  - Return to the science field.
  - Repeat for 12 hours.
- Maintain pointing requirements in tracking mode for each segment.
- Report results of simulation:
  - Settling times,
  - Overall efficiency (% time on source or on calibrator).

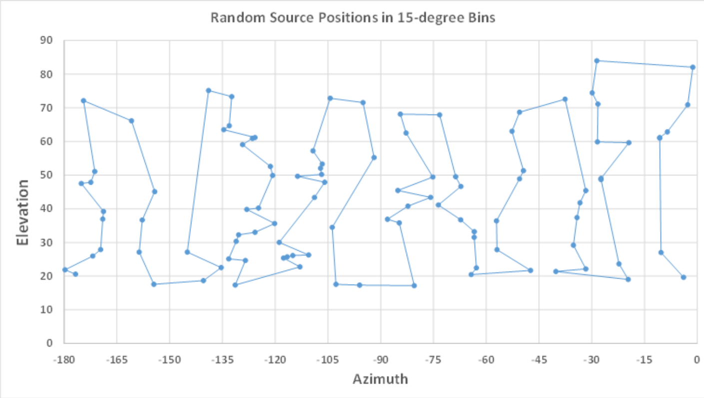
Similar to Use Case A: no separate simulation required.

4.3.6.6.3 Use Case C

<u>Description as Provided by SKA:</u>

C: 3-hour Multi-Source Observation

- Assume the Latitude of the dish is -30 deg.
- Precision conditions (50% day; 50% night).
- 103 sources to be observed for a period of 60 s each.
- Total time on source 1.7 hours.
- Elevation range: 15 - 85°
- Average distance between sources: ~10°
- Observing simulation:
  - Begin at Az = -180°; Elevation = 15°
  - Follow source list as per diagram.



- Report results of simulation:
  - Settling times,
  - Overall efficiency (% time on source).

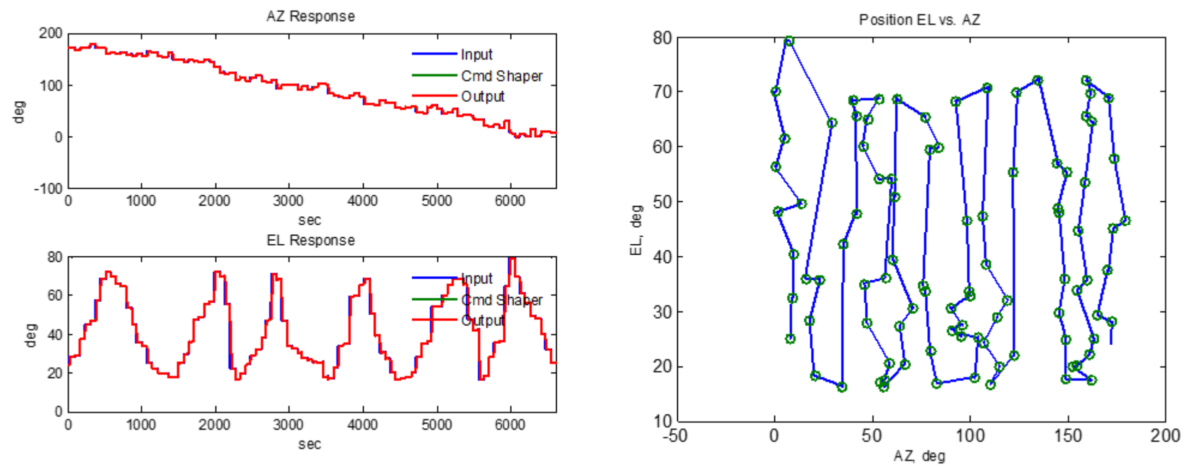
Additional Assumptions:

Input Trajectory:
Input data has been provided in an Excel file ("Random_position_generator_v2.xlsx")

elevation	azimuth	elevation	azimuth
20.60731	-176.748	66.16584	-160.842
21.8919	-179.751	45.10739	-154.275
25.96957	-171.88	36.67942	-157.809
27.8996	-169.636	27.13705	-158.682
36.95296	-169.037	17.57142	-154.503
39.23108	-168.831	20000	20000
47.52436	-175.127	20000	20000
47.88664	-172.398	20000	20000
51.08905	-171.292	20000	20000
72.127	-174.505	20000	20000
20000	20000	20000	20000

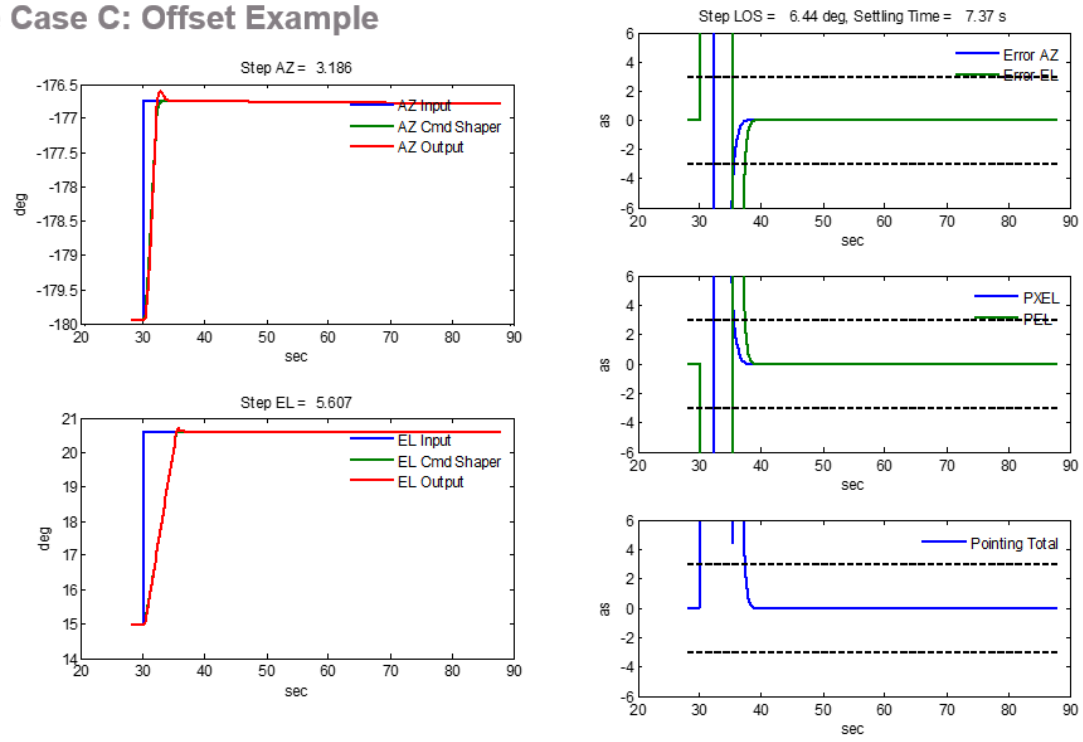
Simulation Results:

Use Case C: System Response

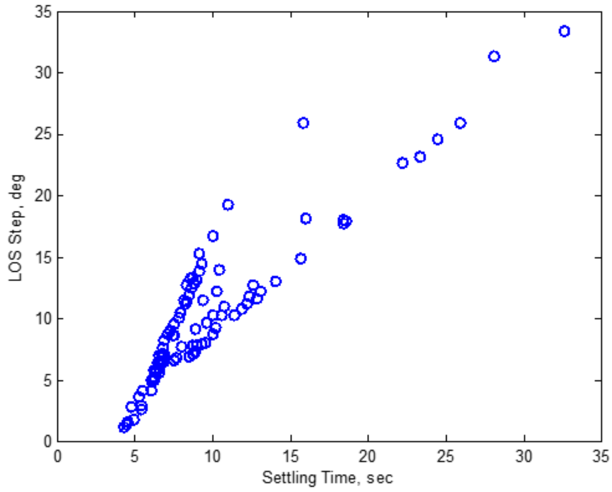


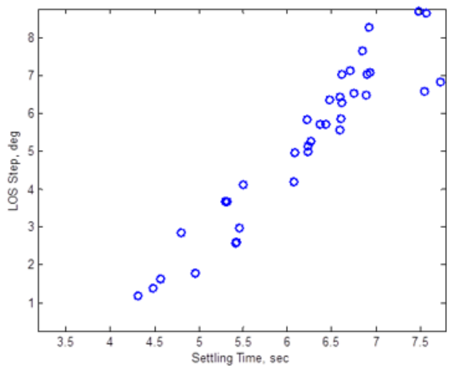
86.6 % on source for 3 arcsec pointing error

Use Case C: Offset Example

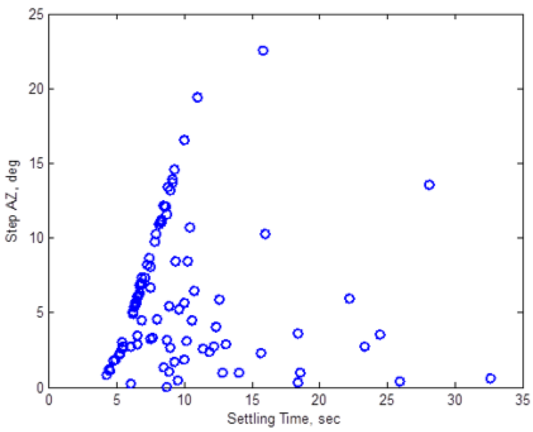


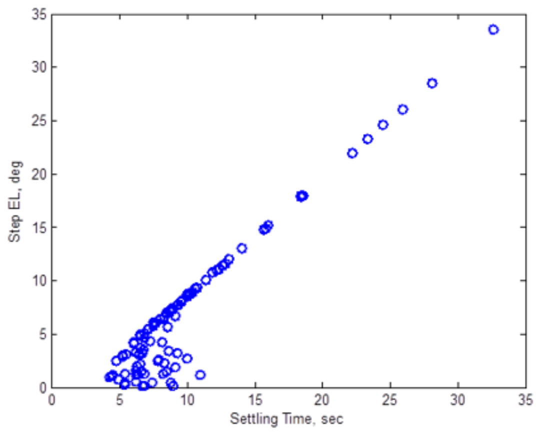
Use Case C: Settling Times Summary





Use Case C: Settling Times Summary





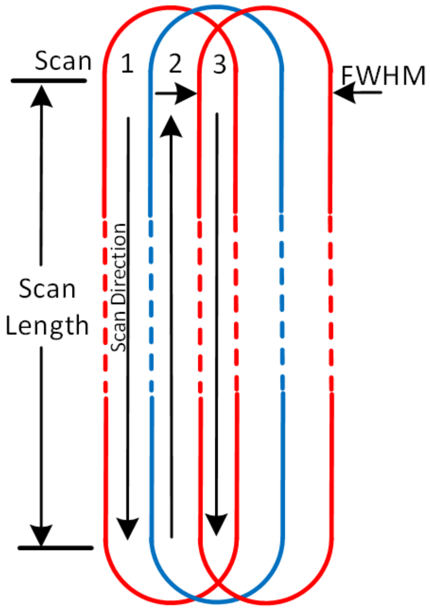
4.3.6.6.4 Use Case D

Description as Provided by SKA:

D: 32-hour N-S Fast Scan

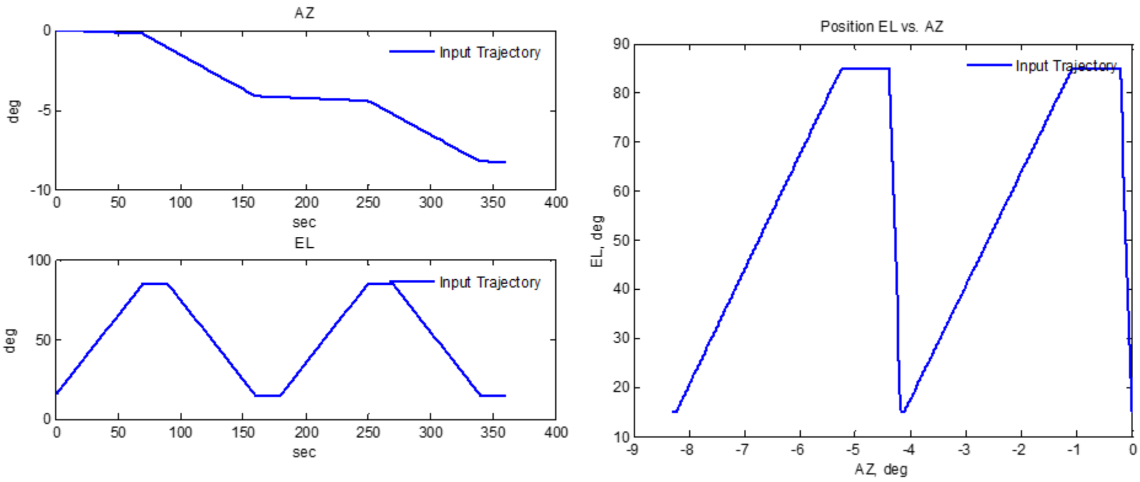
- Begin at a HA = 0; Elevation = 15 deg.
  - Scan at 1.0 deg/s to Elevation = 85 deg. at HA = 0.
  - Scan at 1.0 deg/s to Elevation = 15 deg. at HA = 0.
  - Repeat for 32 hours.
- Precision conditions (50% day; 50% night).
- Maintain fast scanning pointing requirements.
- Precision conditions.

- Report results of simulation:
  - Power usage,
  - Settling times,
  - Overall efficiency (% time taking data).



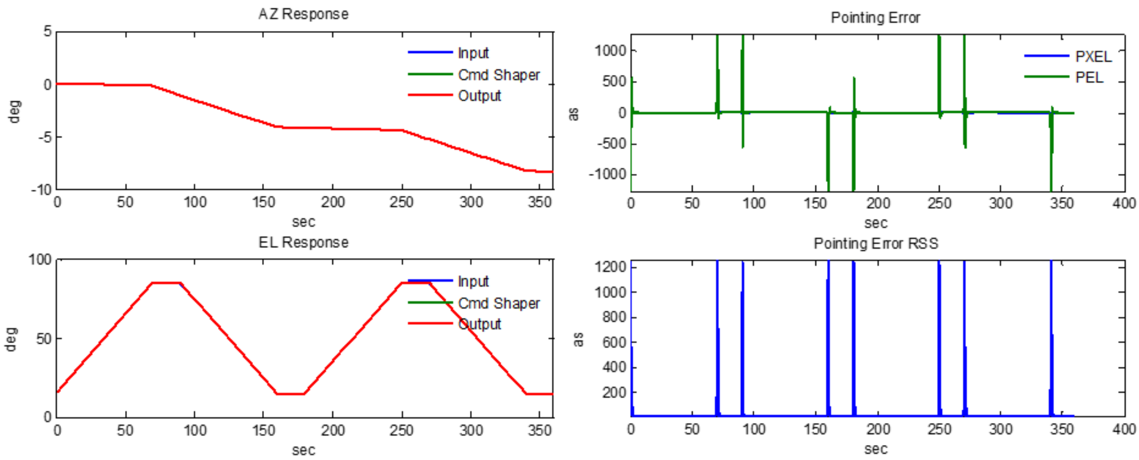
Input Trajectory:

Use Case D: Input Trajectory



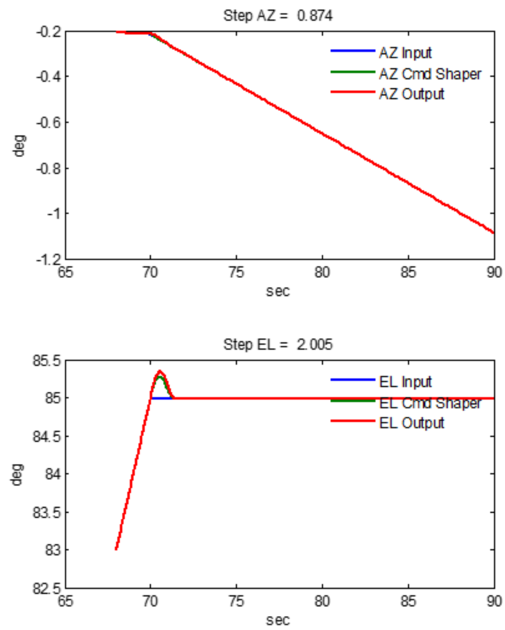
Simulation Results:

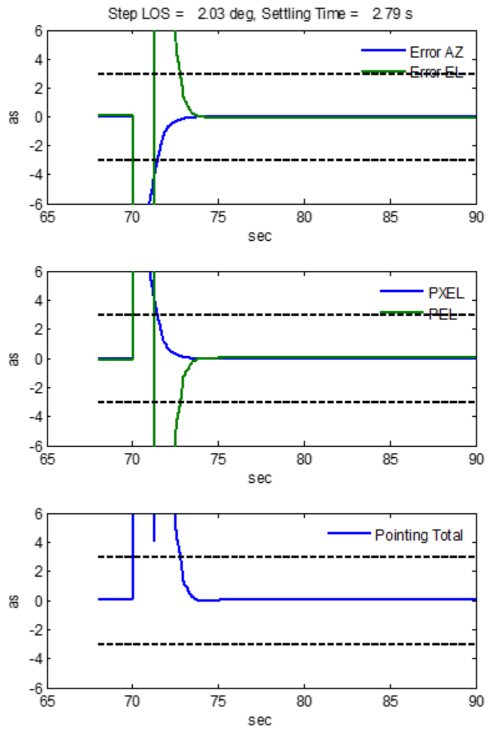
Use Case D: System Response

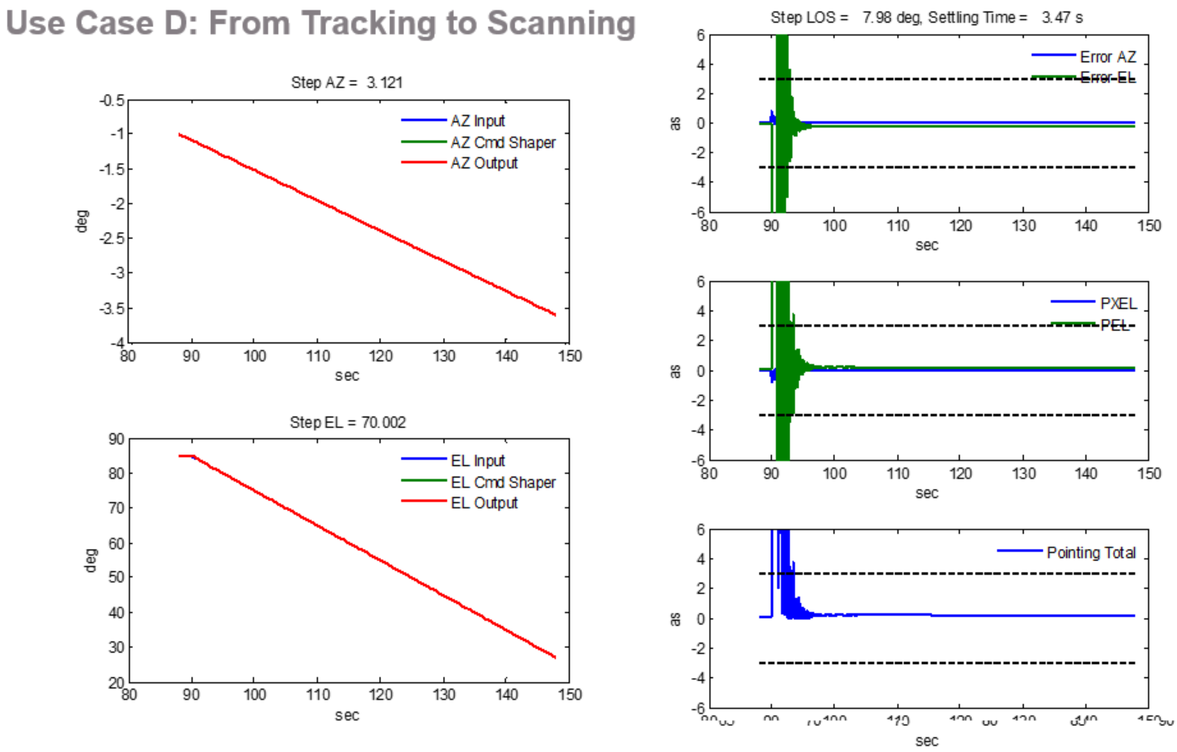


93.9 % on source
for 3 arcsec pointing error

Use Case D: From Scanning to Tracking





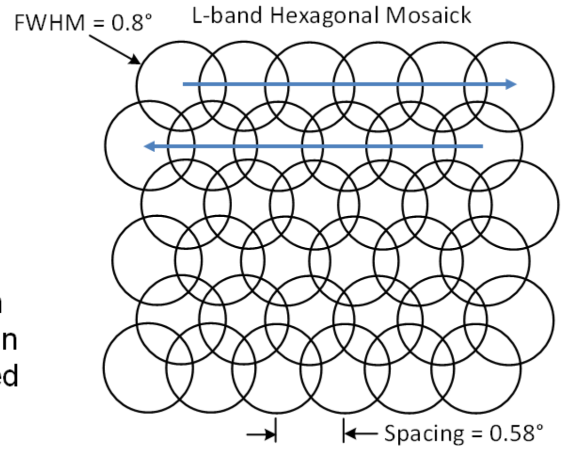


4.3.6.6.5 Use Case E

<u>Description as Provided by SKA:</u>

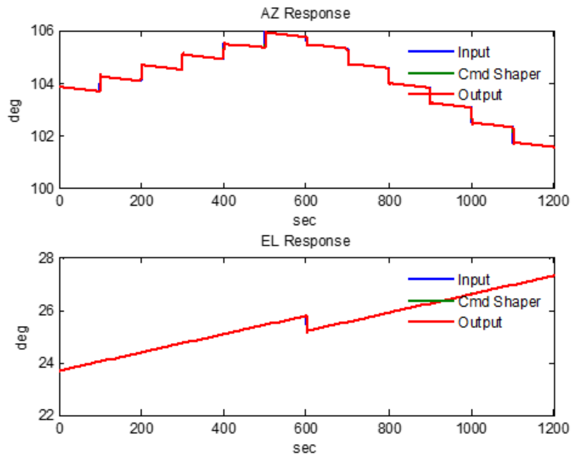
E: L-band Mosaicking Observation

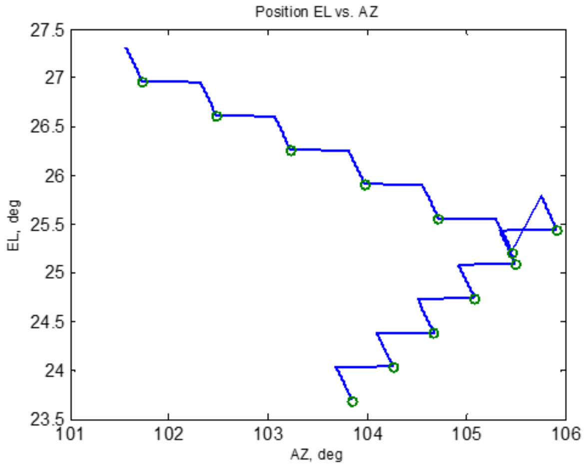
- Over an -5 < HA < 5 hrs, cycle over 36 science fields. Declination -23 deg.
- Precision conditions (50% day; 50% night).
- Beam: FWHM = 0.82 deg.
- Spacing: FWHM / √2
- Hexagonal grid; row by row.
- Integration time per grid position: 100 s.
- After each 3600 s, carry out a calibration on a source 5 deg in east HA and 5 deg north in Declination, in a time sequence as described in Case A.
- Total time on science field: 10 hr.
- Maintain pointing requirements in tracking mode for each field.
- Report results of simulation:
  - Settling times,
  - Overall efficiency (% time on source).



<u>Input Trajectory and Simulation Results:</u>

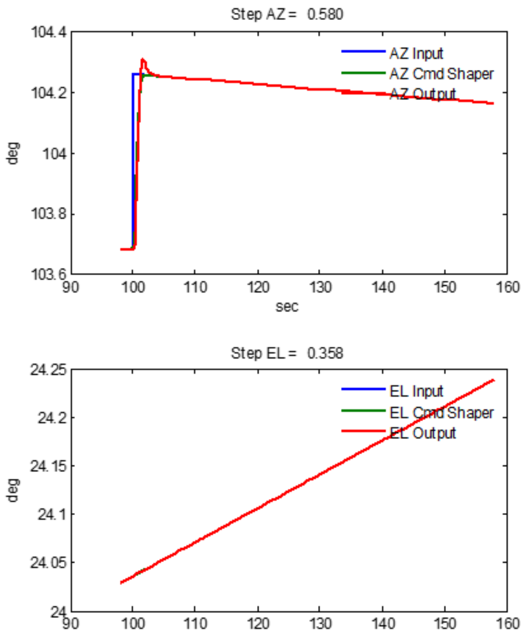
Use Case E: System Response (2 rows)

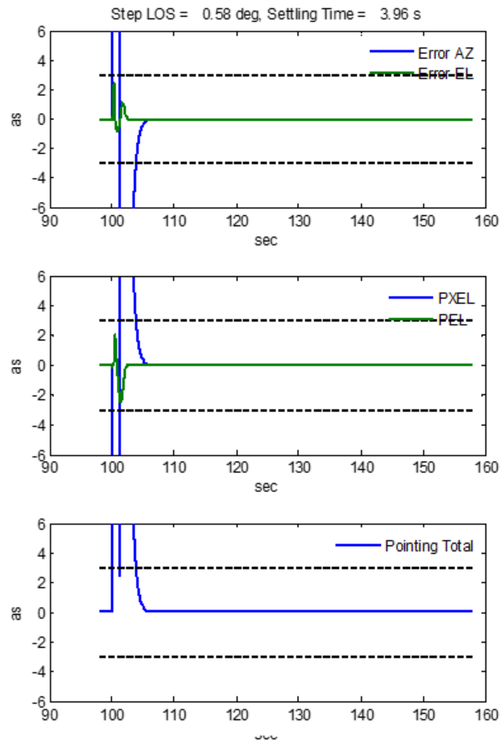


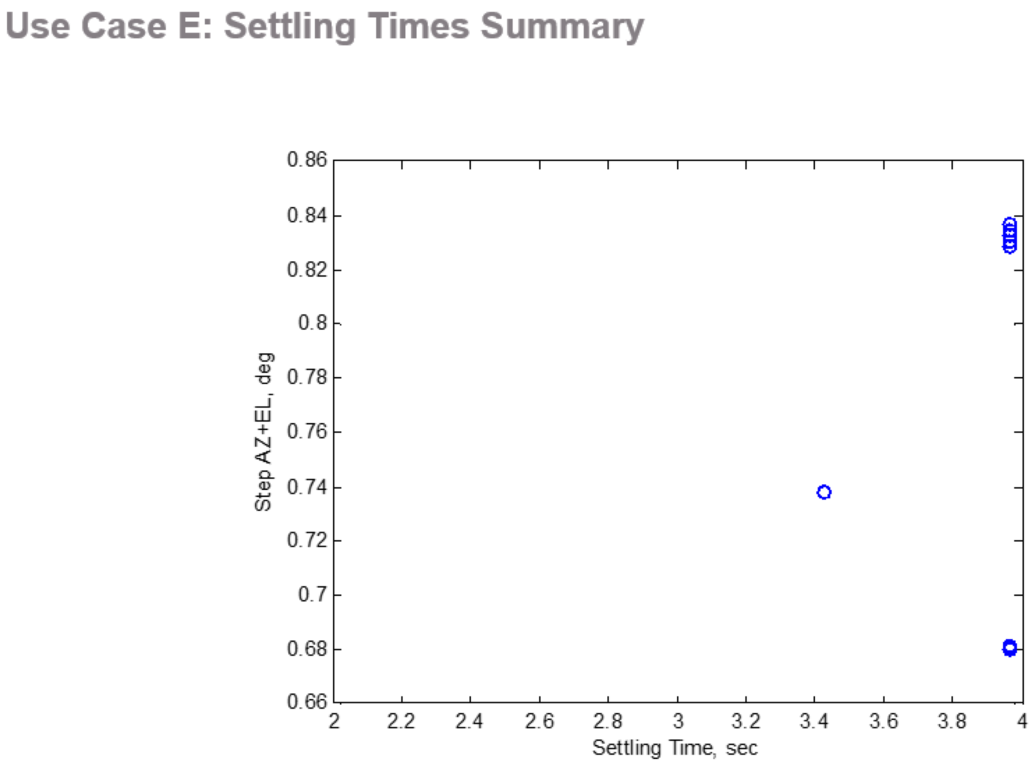


96.4 % on source for 3 arcsec pointing error

Use Case E: Offset Example



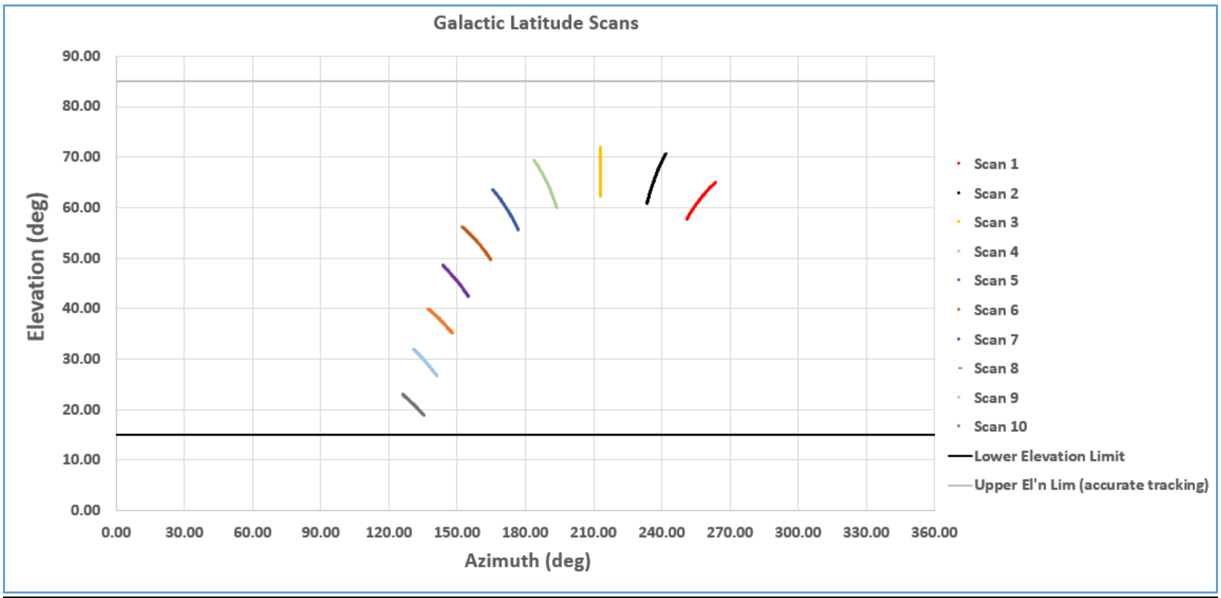




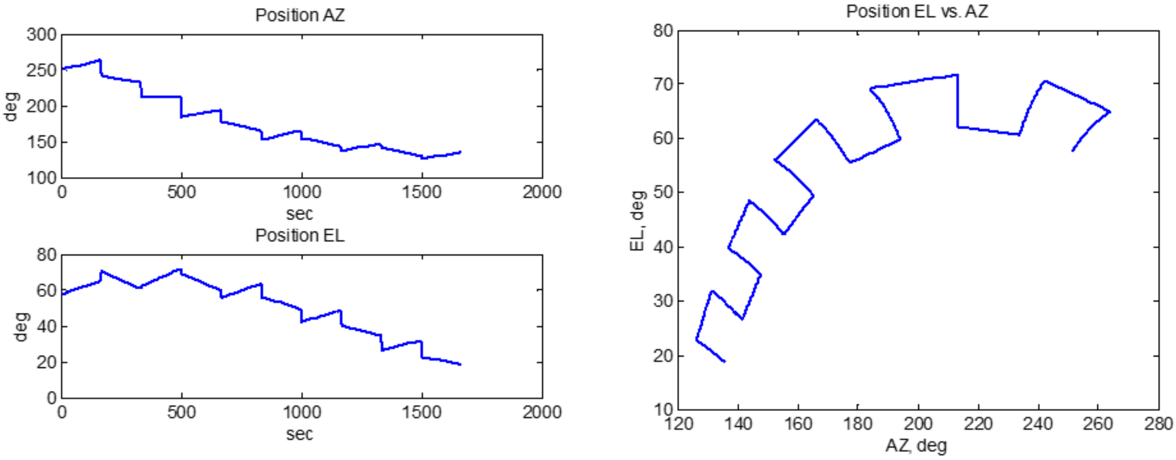
4.3.6.6.6 Use Case F

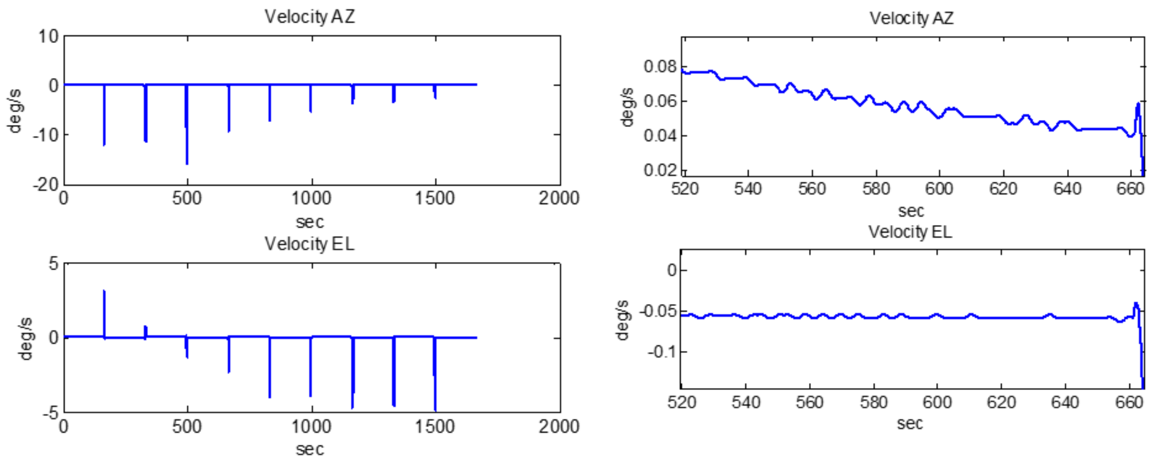
<u>Description as Provided by SKA:</u>

Description and data were provided in an Excel file ("Galactic_Plane_scan_mode_v2.xlsx")



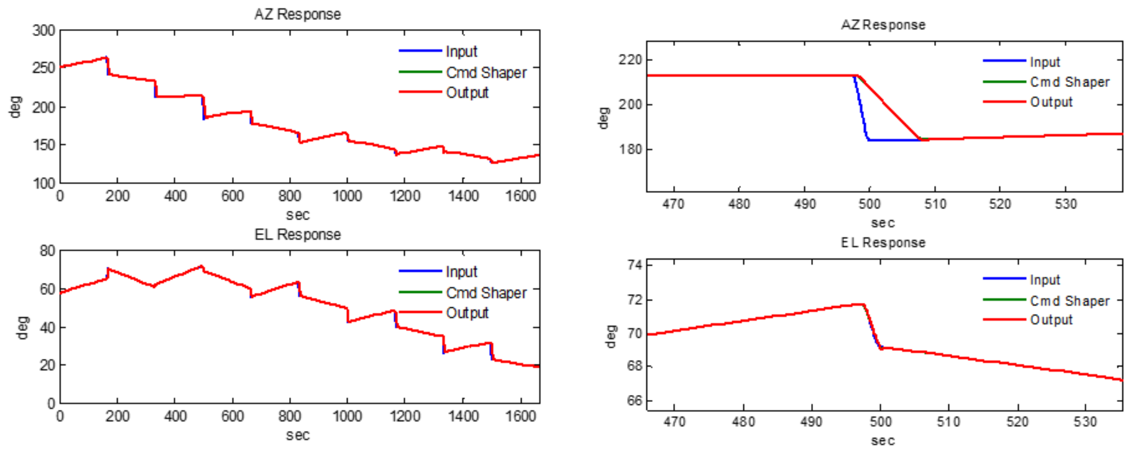
Input Trajectory:



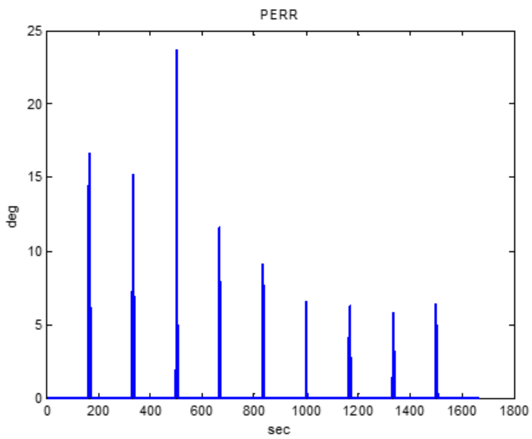


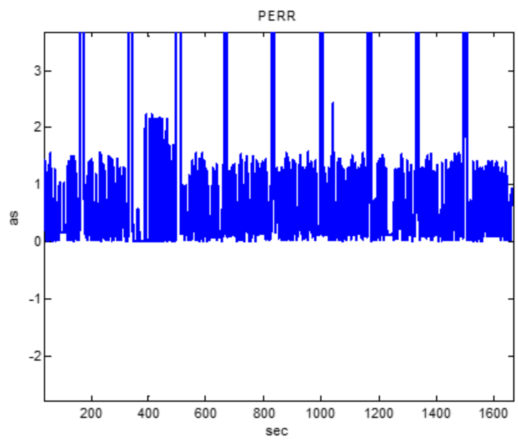
Simulation Results:

Use Case F: System response



Use Case F: Time on source





97.3 % on source for 3 arcsec pointing error

4.4 EMI Shielded Compartment - Provide EMI Shielding

The allocated Shielding Effectiveness requirement is:

- greater than 80 dB for all frequencies from 50 MHz to 13.8 GHz, and

- greater than 60 dB for all frequencies from 13.8GHz to 20GHz.

The vertical and horizontal polarization shielding performance of the cabinet is indicated hereunder. The test results indicate compliance with the requirement.

Figure 286: EMISC Shielding Effectiveness test setup

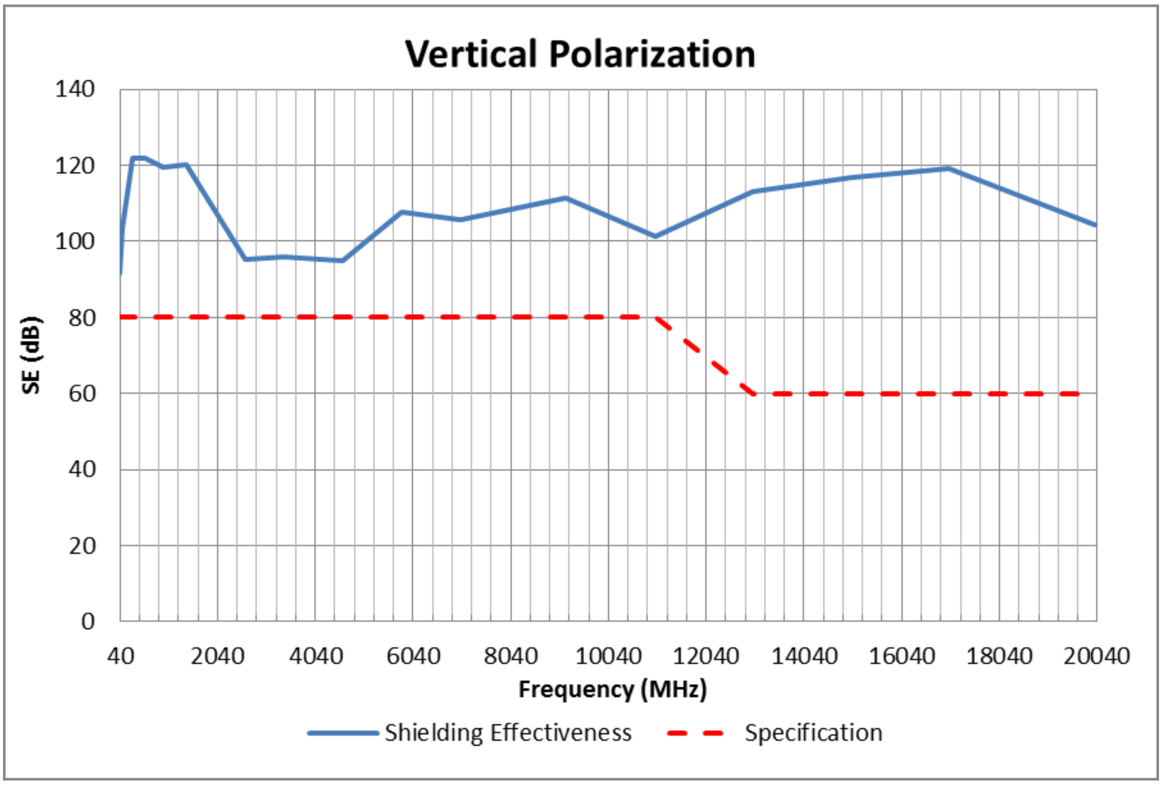


Figure 287: EMISC Shielding Effectiveness test results – Vertical Polarization

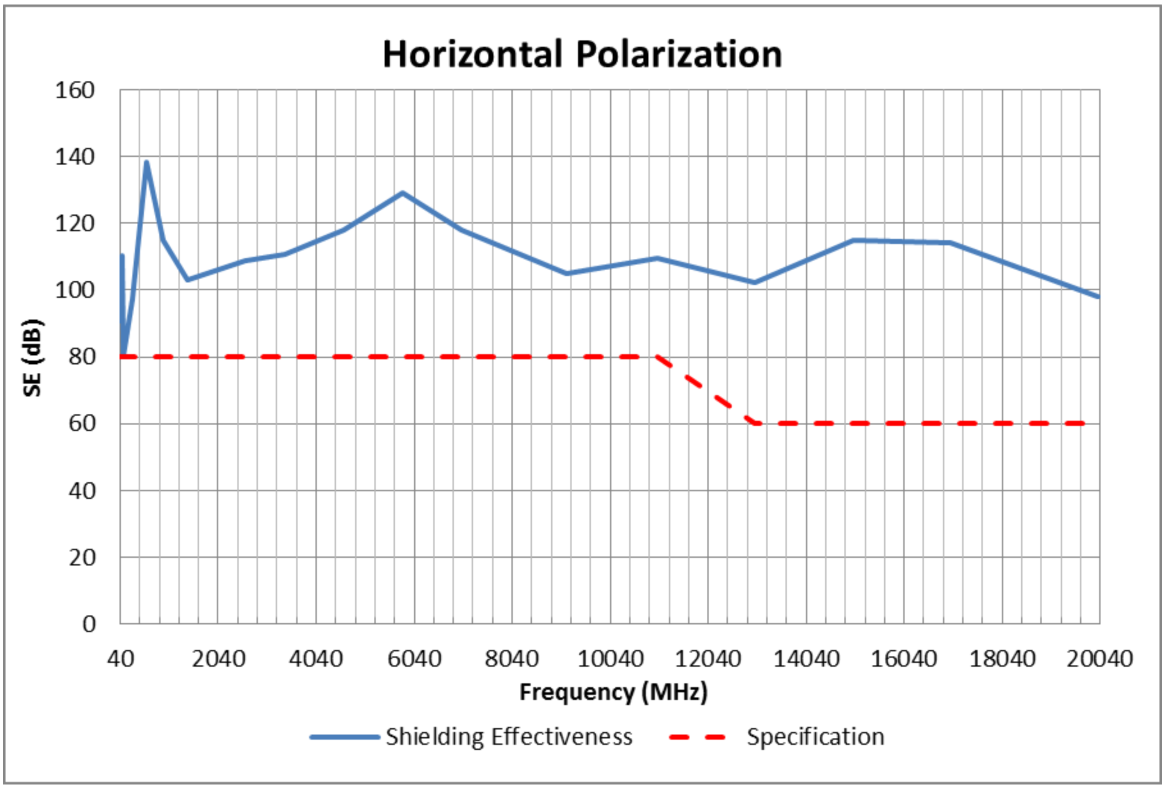


Figure 288: EMISC Shielding Effectiveness test results – Horizontal Polarization

4.5 EMI Shielded Compartment - Provide Environment

The "Provide Environment" function allocated to the EMISC is defined as:

> *Provide an environment with an air temperature of 0℃ to 45℃ inside the cabinet with the outside air temperature of -5℃ to 40℃. This applies to operational conditions.*
> *Note that industry standards define that if equipment is rated for 45℃ it entails that this temperature to be maintained at the air inlet point of the equipment, ie not the overall surround of the equipment.*

Due to the low "power consumption" and "low maintenance" requirements and expectations for the SKA1 Mid Telescope a passive ventilation system of forced ventilation of outside ambient air through the cabinet is adopted. Outside air is circulated through the EMISC by means of fans located inside the cabinet. The interface requirement for the hosted equipment is defined as internal forced airflow (fans) with air circulation front to back. Additional localised rack fans will be installed, if needed, to provide forced airflow for the equipment that makes use of natural convection only.

A thermal analysis of the EMISC was performed. The general setup of the analysis model is illustrate in Figure 289.

The major physical dimensions used in the thermal model are as follows:

Cabinet:	2098 mm (height) x 610 mm (width) x 937 mm (depth)
Ventilation outlet:	450 mm (length) x 150 mm (width), 50 mm from rear wall
Ventilation inlet:	360 mm (length) x 150 mm (width), 67 mm from front wall

The ventilation intake and outlets are fitted with filters representing the airflow characteristics of the attenuvents to be fitted on the final product. The equipment was modelled as uniform heat sources of "hot airflow" provided by their internal fans.

Since this analysis was performed in isolation from the PSC, the cabinet was surrounded by air with temperature of average 47°C, allowing natural airflow, to emulate the conditions within the PSC. Since the EMISC is located inside the PSC the air intake points are located to allow the cooler outside air to enter the EMISC directly to minimise the impact of the other heat sources inside the PSC. The inlet air temperature is therefore taken as the maximum ambient temperature of 40°C.

Various positions for the inlet and outlet openings and positions for the fan(s) were evaluated. The preferred solution is the intake opening at the bottom front floor of the cabinet and the outlet at the rear of the roof. The optimal position of the three fans was found to be at the outlet.

Various stack-up configurations were evaluated to optimise between airflow, heat load distribution, access for maintenance and initial installation and cable routing. Baffle plates were introduced in order to optimise airflow. The proposed stack-up of the equipment and baffle configuration are illustrated in Figure 289.

A summary of the results are shown in Figure 299. The air temperature at the air intake points of the equipment is ~40°C. The maximum average surrounding air temperature is less than ~47°C with peak hotspots close to the airflow exit points of ~60°C. The airflow at the bottom of the cabinet (close to the SPF Controller) is stagnant causing local hotspots of up to ~67°C. This will be corrected by means of a rack-fan unit installed at the SPF Controller. Note that it is foreseen that a final test will be performed on a fully populated EMISC during the qualification phase in order to optimise the airflow and location of additional rack-fans.

Based on the results from the analysis and the planned tests to be performed on the final populated cabinet it can be stated that the air temperature inside the cabinet will comply with the requirement.

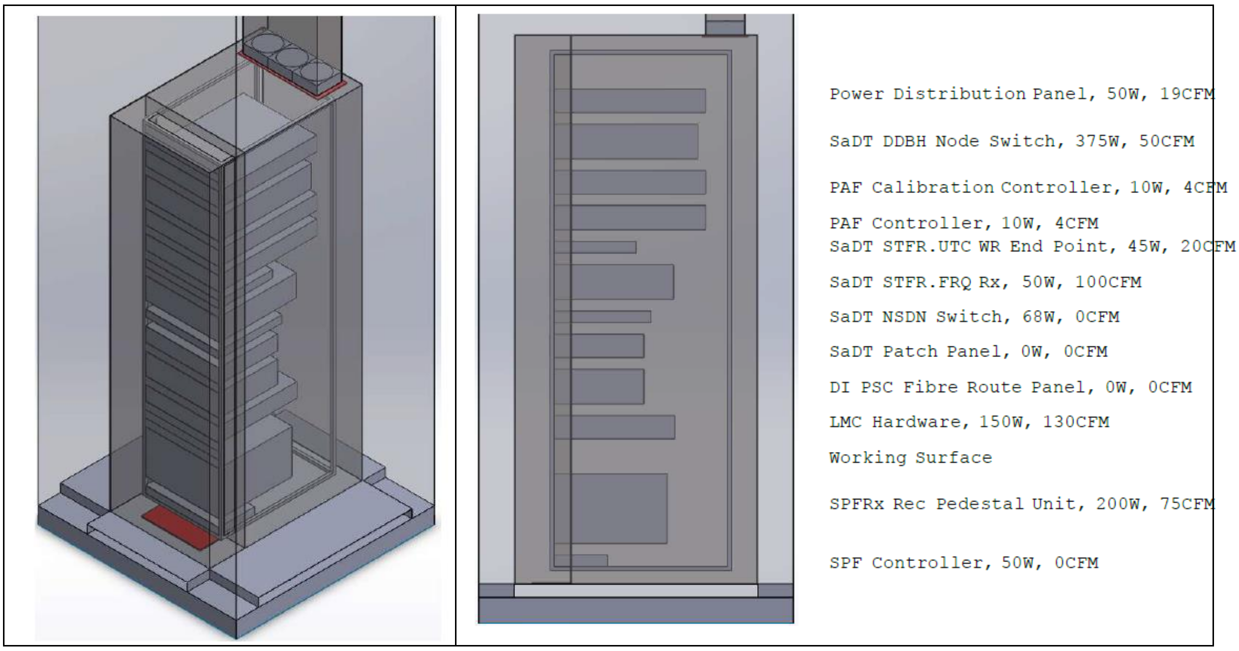


Figure 289: EMISC Stack-Up for Thermal Analysis

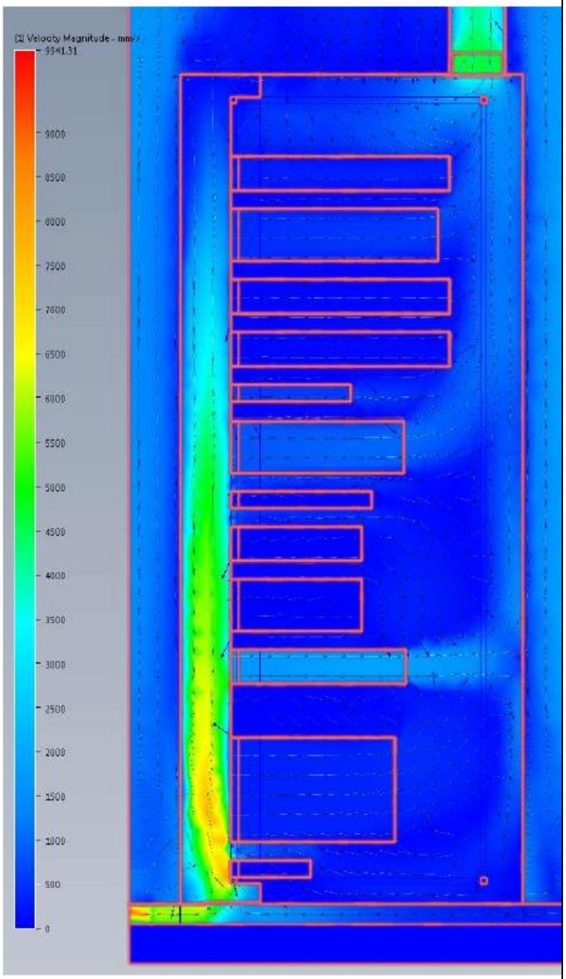
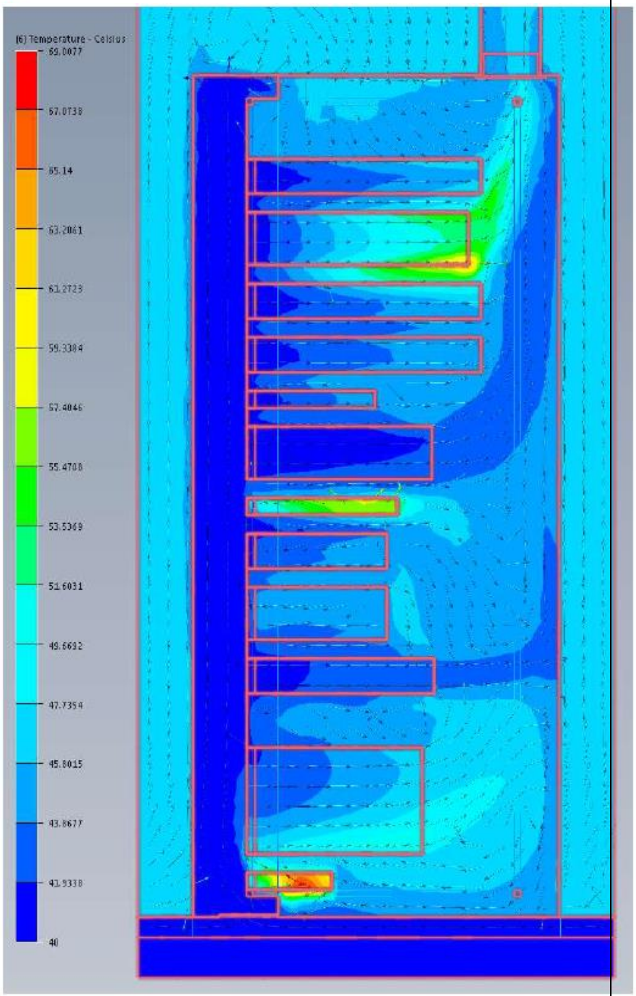
Airflow	Temperature
	

Figure 290: EMISC Thermal Analysis Results

4.6 Power Budget and Measuring of Consumption

The power budget for the Dish Structure is stated in

Requirements & Inputs

Elevation slew rate	1		°/sec
Azimuth slew rate	3		°/sec
Indexer switching time	30		sec
Operational Wind (Precision)	5		m/sec
Operational Wind (Standard)	7		m/sec
Operational Wind (Degraded)	10		m/sec
Stow Wind (Extreme)	20		m/sec
Galactic Scan average speed	0.06		°/sec
Fast Scan Speed (elevation)	0.01 (az)	0.500 (el)	°/sec
Fast Scan Speed (azimuth)	0.50 (az)	0.010 (el)	°/sec
Maximum allowed degradation under extreme conc	50%		
Maximum allowed degradation under degraded cor	75%		
Allowed degradation during back-up stow	50%		
Combined stow time (degraded)	150		sec
Sequential stow time (degraded)	210		sec
Combined stow time (100%)	75		sec
Sequential stow time (100%)	105		sec
Stow waiting time on power failure (UPS state)	10		sec

Scenario:	no wind		operational wind (precision)		operational wind (standard)		operational wind (degraded)			extreme wind			
	track [W]	slew [W]	track [W]	slew [W]	track [W]	slew [W]	track [W]	slew [W]		track [W]	slew [W]		
								100%	degraded		100%	degraded	
Continous load (Control System)	650.0	-	650.0	-	650.0	-	650.0	-		650.0	-	-	
Continous load (EMISC losses)	45.0	-	45.0	-	45.0	-	45.0			45.0	-	-	
Az/El combined tracking (1a) [Servo's only]	782	-	1048	-	1303	-	1845	-		5035	-	-	
Az/El combined tracking (1b) [Servo's only]	782	-	932	-	1077	-	1383	-		3187	-	-	
El slew (2a) [Servo's only]	-	4991	-	5270	-	5537	-	6106	5537	-	9450	5537	
El slew (2b) [Servo's only]	-	2468	-	2688	-	2898	-	3346	2898	-	5981	2898	
Az slew (3) [Servo's only]	-	2734	-	3452	-	4141	-	5606	4141	-	14223	4141	
Az/El combined slew (4a) [Servo's only]	-	7725	-	8323	-	8897	-	10117	8897	-	17294	8897	
Az/El combined slew (4b) [Servo's only]	-	5202	-	7314	-	7888	-	9108	7888	-	16285	7888	
Indexer switching (5a) [Servo's only]	-	400	-	400	-	400	-	400	400	-	400	400	
Cooling (Drive Cabinet)	200												
Cooling (PSC)	375												
Cooling (EMISC)	135												
UPS running	*0*												
UPS (losses)	10%												
UPS (charging)	*0*												
Other DISH equipment running from UPS	1100												
Slew Elevation only	6965		7271		7565		8191		7565	11870		7565	
Slew Azimuth only	4482		5272		6030		7641		6030	17120		6030	**Max Short Term Average**
Index	1915		1915		1915		1915		1915	1915		1915	
Slew all axes	10412		11070		11701		13043		11701	20938		11701	
Stow	10412		11070		11701		13043		11701	20938		11701	
Fast Scan (elevation)	2842		2965		3084		3335		3084	4816		3084	
Fast Scan (azimuth)	2031		2165		2295		2569		2295	4186		2295	
Galactic Scan	1708		1729		1748		1790		1748	2036		1748	**Long Term Average**
Observing	2494		2847		3138		3757		3717	7398		7121	
Pointing Calibration	2573		2947		3242		3868		3814	7552		7183	
Idle	1475		1475		1475		1475		1475	1475		1475	
Start-up	38198												**Peak Instantane**
Acceleration	11453		12177		12872		14348		12872	23031		12872	

(1a) Track at 0.05 °/sec (worst case elevation unbalance)
(1b) Track at 0.05 °/sec (average elevation unbalance)
(2a) Slew in elevation with worst case wind attitude (maximum elevation unbalance) conservative - these loads may cancel out, but we simply add them here
(2b) Slew in elevation with worst case wind attitude (average elevation unbalance) conservative - these loads may cancel out, but we simply add them here
(3) Slew in azimuth at the maximum slew rate under the worst case wind attitude.
(4a) Slew in both axis at maximum slew rate under the worst case combined wind attitude (maximum el conservative - these loads may cancel out, but we simply add them here
(4b) Slew in both axis at maximum slew rate under the worst case combined wind attitude (average elev conservative - these loads may cancel out, but we simply add them here
(5a) Indexer slew (maximum indexer unbalance at maximum elevation angle)

	Azimuth	Elevation	Indexer	Distribution	
Duty cycle Observation:	3%	3%	3%	54%	Relative pointing & tracking
Duty cycle Pointing Calibration:	3%	5%	10%	5%	Pointing Model Calibratoin
Downtime :				5%	Bad weather & maintenance
Combined Wind Direction factor :	0.6				
Acceleration factor :	1.1				

Table 55. The first section states the individual contributors (types of load) and the second section states the summation for different categories and duty cycles. These catogories are defined by the SKAO and is explained below.

- **Max Short Term Average:** ***This is the expected short term (5 sec - 10 min) maximum steady-state average power than will be consumed during normal operation. This includes the system full operation. Examples of this might include high speed slewing of***

dishes or full power operation of cooling systems during initial chill-down. This value will assist in investigating the possibility of sequencing devices, using local backup power to smooth load peaks, and for calculating worst case demand.

- **Long Term Average:** ***This is the expected average power consumption over long timescales of tens of minutes to hours. This can be seen as the normal operating power consumption of the device. The power system will primarily be sized to this value.***
- **Peak Instantanious:** ***This is the expected maximum peak power consumption value during transient operations. It is expected that this is the highest power that the device will consume for no longer than a few seconds. Examples of this might include the Direct-On-Line (DOL) starting of an induction motor. This value is reported in VA, since it is often difficult to obtain a Watt value due the poor power factor during transients. This value will assist in the estimation of voltage dips and sizing of distribution systems.***

The total power consumption allocated to the dish structure as stated in

Requirements & Inputs

Elevation slew rate	1	°/sec
Azimuth slew rate	3	°/sec
Indexer switching time	30	sec
Operational Wind (Precision)	5	m/sec
Operational Wind (Standard)	7	m/sec
Operational Wind (Degraded)	10	m/sec
Stow Wind (Extreme)	20	m/sec
Galactic Scan average speed	0.06	°/sec
Fast Scan Speed (elevation)	0.01 (az) 0.500 (el)	°/sec
Fast Scan Speed (azimuth)	0.50 (az) 0.010 (el)	°/sec
Maximum allowed degradation under extreme conc	50%	
Maximum allowed degradation under degraded cor	75%	
Allowed degradation during back-up stow	50%	
Combined stow time (degraded)	150	sec
Sequential stow time (degraded)	210	sec
Combined stow time (100%)	75	sec
Sequential stow time (100%)	105	sec
Stow waiting time on power failure (UPS state)	10	sec

Scenario:	no wind		operational wind (precision)		operational wind (standard)		operational wind (degraded)			extreme wind		
	track [W]	slew [W]	track [W]	slew [W]	track [W]	slew [W]	track [W]	slew [W] 100%	slew [W] degraded	track [W]	slew [W] 100%	slew [W] degraded
Continous load (Control System)	650.0	-	650.0	-	650.0	-	650.0	-		650.0	-	-
Continous load (EMISC losses)	45.0	-	45.0	-	45.0	-	45.0			45.0	-	-
Az/El combined tracking (1a) [Servo's only]	782	-	1048	-	1303	-	1845	-		5035	-	-
Az/El combined tracking (1b) [Servo's only]	782	-	932	-	1077	-	1383	-		3187	-	-
El slew (2a) [Servo's only]	-	4991	-	5270	-	5537	-	6106	5537	-	9450	5537
El slew (2b) [Servo's only]	-	2468	-	2688	-	2898	-	3346	2898	-	5981	2898
Az slew (3) [Servo's only]	-	2734	-	3452	-	4141	-	5606	4141	-	14223	4141
Az/El combined slew (4a) [Servo's only]	-	7725	-	8323	-	8897	-	10117	8897	-	17294	8897
Az/El combined slew (4b) [Servo's only]	-	5202	-	7314	-	7888	-	9108	7888	-	16285	7888
Indexer switching (5a) [Servo's only]	-	400	-	400	-	400	-	400	400	-	400	400
Cooling (Drive Cabinet)	200											
Cooling (PSC)	375											
Cooling (EMISC)	135											
UPS running	0											
UPS (losses)	10%											
UPS (charging)	0											
Other DISH equipment running from UPS	1100											

Slew Elevation only	6965	7271	7565	8191	7565	11870	7565	
Slew Azimuth only	4482	5272	6030	7641	6030	17120	6030	Max Short
Index	1915	1915	1915	1915	1915	1915	1915	Term
Slew all axes	10412	11070	11701	13043	11701	20938	11701	Average
Stow	10412	11070	11701	13043	11701	20938	11701	
Fast Scan (elevation)	2842	2965	3084	3335	3084	4816	3084	
Fast Scan (azimuth)	2031	2165	2295	2569	2295	4186	2295	
Galactic Scan	1708	1729	1748	1790	1748	2036	1748	Long Term
Observing	2494	2847	3138	3757	3717	7398	7121	Average
Pointing Calibration	2573	2947	3242	3868	3814	7552	7183	
Idle	1475	1475	1475	1475	1475	1475	1475	
Start-up	38198							Peak
Acceleration	11453	12177	12872	14348	12872	23031	12872	Instantane

(1a) Track at 0.05 °/sec (worst case elevation unbalance)
(1b) Track at 0.05 °/sec (average elevation unbalance)
(2a) Slew in elevation with worst case wind attitude (maximum elevation unbalance) conservative - these loads may cancel out, but we simply add them here
(2b) Slew in elevation with worst case wind attitude (average elevation unbalance) conservative - these loads may cancel out, but we simply add them here
(3) Slew in azimuth at the maximum slew rate under the worst case wind attitude.
(4a) Slew in both axis at maximum slew rate under the worst case combined wind attitude (maximum el conservative - these loads may cancel out, but we simply add them here
(4b) Slew in both axis at maximum slew rate under the worst case combined wind attitude (average elev conservative - these loads may cancel out, but we simply add them here
(5a) Indexer slew (maximum indexer unbalance at maximum elevation angle)

	Azimuth	Elevation	Indexer	Distribution	
Duty cycle Observation:	3%	3%	3%	54%	Relative pointing & tracking
Duty cycle Pointing Calibration:	3%	5%	10%	5%	Pointing Model Calibratoin
Downtime :				5%	Bad weather & maintenance
Combined Wind Direction factor :	0.6				
Acceleration factor :	1.1				

Table 55 is as follows:

- **Max Short Term Average: 6750 W**
- **Long Term Average: 2850 W**
- **Peak Instantanious: 23170 W**

Note that this original allocation were based on a typical "Observation" duty cycle under Standard Operating Conditions only, and excluded any scanning type duty cycle. Additionally the azimuth maximum slew rate was defined as 2°/sec, this requirement has since changed to 3°/sec.

As indicated in "Bold & Red" text in the bottom section of

Requirements & Inputs

Elevation slew rate	1	°/sec
Azimuth slew rate	3	°/sec
Indexer switching time	30	sec
Operational Wind (Precision)	5	m/sec
Operational Wind (Standard)	7	m/sec
Operational Wind (Degraded)	10	m/sec
Stow Wind (Extreme)	20	m/sec
Galactic Scan average speed	0.06	°/sec
Fast Scan Speed (elevation)	0.01 (az) 0.500 (el)	°/sec
Fast Scan Speed (azimuth)	0.50 (az) 0.010 (el)	°/sec
Maximum allowed degradation under extreme conc	50%	
Maximum allowed degradation under degraded cor	75%	
Allowed degradation during back-up stow	50%	
Combined stow time (degraded)	150	sec
Sequential stow time (degraded)	210	sec
Combined stow time (100%)	75	sec
Sequential stow time (100%)	105	sec
Stow waiting time on power failure (UPS state)	10	sec

Scenario:	no wind		operational wind (precision)		operational wind (standard)		operational wind (degraded)			extreme wind		
	track [W]	slew [W]	track [W]	slew [W]	track [W]	slew [W]	track [W]	slew [W] 100%	slew [W] degraded	track [W]	slew [W] 100%	slew [W] degraded
Continous load (Control System)	650.0	-	650.0	-	650.0	-	650.0	-		650.0	-	-
Continous load (EMISC losses)	45.0	-	45.0	-	45.0	-	45.0			**45.0**	-	-
Az/El combined tracking (1a) [Servo's only]	782	-	1048	-	1303	-	1845	-		5035	-	-
Az/El combined tracking (1b) [Servo's only]	782	-	932	-	1077	-	1383	-		3187	-	-
El slew (2a) [Servo's only]	-	4991	-	5270	-	5537	-	6106	5537	-	9450	5537
El slew (2b) [Servo's only]	-	2468	-	2688	-	2898	-	3346	2898	-	5981	2898
Az slew (3) [Servo's only]	-	2734	-	3452	-	4141	-	5606	4141	-	14223	4141
Az/El combined slew (4a) [Servo's only]	-	7725	-	8323	-	8897	-	10117	8897	-	17294	8897
Az/El combined slew (4b) [Servo's only]	-	5202	-	7314	-	7888	-	9108	7888	-	16285	7888
Indexer switching (5a) [Servo's only]	-	400	-	400	-	400	-	400	400	-	400	400
Cooling (Drive Cabinet)	**200**											
Cooling (PSC)	375											
Cooling (EMISC)	135											
UPS running	*0*											
UPS (losses)	10%											
UPS (charging)	*0*											
Other DISH equipment running from UPS	1100											

	no wind	operational wind (precision)	operational wind (standard)	operational wind (degraded) 100%	operational wind (degraded) degraded	extreme wind 100%	extreme wind degraded	
Slew Elevation only	6965	7271	7565	8191	7565	11870	7565	**Max Short Term Average**
Slew Azimuth only	4482	5272	6030	7641	6030	17120	6030	
Index	1915	1915	1915	1915	1915	1915	1915	
Slew all axes	10412	11070	11701	13043	11701	20938	11701	
Stow	10412	11070	11701	13043	11701	20938	11701	
Fast Scan (elevation)	2842	2965	3084	3335	3084	4816	3084	**Long Term Average**
Fast Scan (azimuth)	2031	2165	2295	2569	2295	4186	2295	
Galactic Scan	1708	1729	1748	1790	1748	2036	1748	
Observing	2494	2847	3138	3757	3717	7398	7121	
Pointing Calibration	2573	2947	3242	3868	3814	7552	7183	
Idle	1475	1475	1475	1475	1475	1475	1475	
Start-up	38198							**Peak Instantane**
Acceleration	11453	12177	12872	14348	12872	23031	12872	

(1a) Track at 0.05 °/sec (worst case elevation unbalance)
(1b) Track at 0.05 °/sec (average elevation unbalance)
(2a) Slew in elevation with worst case wind attitude (maximum elevation unbalance) conservative - these loads may cancel out, but we simply add them here
(2b) Slew in elevation with worst case wind attitude (average elevation unbalance) conservative - these loads may cancel out, but we simply add them here
(3) Slew in azimuth at the maximum slew rate under the worst case wind attitude.
(4a) Slew in both axis at maximum slew rate under the worst case combined wind attitude (maximum el conservative - these loads may cancel out, but we simply add them here
(4b) Slew in both axis at maximum slew rate under the worst case combined wind attitude (average elev conservative - these loads may cancel out, but we simply add them here
(5a) Indexer slew (maximum indexer unbalance at maximum elevation angle)

	Azimuth	Elevation	Indexer	Distribution	
Duty cycle Observation:	3%	3%	3%	54%	Relative pointing & tracking
Duty cycle Pointing Calibration:	3%	5%	10%	5%	Pointing Model Calibratoin
Downtime :				5%	Bad weather & maintenance
Combined Wind Direction factor :	0.6				
Acceleration factor :	1.1				

Table 55, the DS exceeds the allocated power consumption in many cases. The main contributors are the wind speed, elevation unbalance and the higher than previous azimuth slew rate. Note that the DS power budget assumes the worst case wind load, which is very dependant on the wind direction and elevation angle, and is therefor concervative when evaluating the long term average during the fast scan modes. The elevation unbalance load is also variable with elevation and in some cases the worst case unbalance is used.

Note that the fast scan modes are currently not included in the L1 requirements and is based on preliminary outputs from SKAO working groups. It is clear that the Fast Scan modes requires higher average power consumption and will have to be managed on Telescope System level by either limiting the scan speed and/or limiting the number of Dishes that is performing these scans simultaniously.

In order to keep the peak power consumption to reasonable values the DS have the functionality limit its power consumption by gradually degrading the performance as the wind load increases. This thershold is configurable on the remote interface.

Requirements & Inputs

Elevation slew rate	1	°/sec
Azimuth slew rate	3	°/sec
Indexer switching time	30	sec
Operational Wind (Precision)	5	m/sec
Operational Wind (Standard)	7	m/sec
Operational Wind (Degraded)	10	m/sec
Stow Wind (Extreme)	20	m/sec
Galactic Scan average speed	0.06	°/sec
Fast Scan Speed (elevation)	0.01 (az) 0.500 (el)	°/sec
Fast Scan Speed (azimuth)	0.50 (az) 0.010 (el)	°/sec
Maximum allowed degradation under extreme conc	50%	
Maximum allowed degradation under degraded cor	75%	
Allowed degradation during back-up stow	50%	
Combined stow time (degraded)	150	sec
Sequential stow time (degraded)	210	sec
Combined stow time (100%)	75	sec
Sequential stow time (100%)	105	sec
Stow waiting time on power failure (UPS state)	10	sec

Scenario:	no wind		operational wind (precision)		operational wind (standard)		operational wind (degraded)			extreme wind		
	track [W]	slew [W]	track [W]	slew [W]	track [W]	slew [W]	track [W]	slew [W] 100%	slew [W] degraded	track [W]	slew [W] 100%	slew [W] degraded
Continous load (Control System)	650.0	-	650.0	-	650.0	-	650.0	-		650.0	-	-
Continous load (EMISC losses)	45.0	-	45.0	-	45.0	-	45.0			45.0	-	-
Az/El combined tracking (1a) [Servo's only]	782	-	1048	-	1303	-	1845	-		5035	-	-
Az/El combined tracking (1b) [Servo's only]	782	-	932	-	1077	-	1383	-		3187	-	-
El slew (2a) [Servo's only]	-	4991	-	5270	-	5537	-	6106	5537	-	9450	5537
El slew (2b) [Servo's only]	-	2468	-	2688	-	2898	-	3346	2898	-	5981	2898
Az slew (3) [Servo's only]	-	2734	-	3452	-	4141	-	5606	4141	-	14223	4141
Az/El combined slew (4a) [Servo's only]	-	7725	-	8323	-	8897	-	10117	8897	-	17294	8897
Az/El combined slew (4b) [Servo's only]	-	5202	-	7314	-	7888	-	9108	7888	-	16285	7888
Indexer switching (5a) [Servo's only]	-	400	-	400	-	400	-	400	400	-	400	400
Cooling (Drive Cabinet)	200											
Cooling (PSC)	375											
Cooling (EMISC)	135											
UPS running	0											
UPS (losses)	10%											
UPS (charging)	0											
Other DISH equipment running from UPS	1100											

Slew Elevation only	6965	7271	7565	8191	7565	11870	7565	
Slew Azimuth only	4482	5272	6030	7641	6030	17120	6030	Max Short
Index	1915	1915	1915	1915	1915	1915	1915	Term
Slew all axes	10412	11070	11701	13043	11701	20938	11701	Average
Stow	10412	11070	11701	13043	11701	20938	11701	
Fast Scan (elevation)	2842	2965	3084	3335	3084	4816	3084	
Fast Scan (azimuth)	2031	2165	2295	2569	2295	4186	2295	
Galactic Scan	1708	1729	1748	1790	1748	2036	1748	Long Term
Observing	2494	2847	3138	3757	3717	7398	7121	Average
Pointing Calibration	2573	2947	3242	3868	3814	7552	7183	
Idle	1475	1475	1475	1475	1475	1475	1475	
Start-up	38198							Peak
Acceleration	11453	12177	12872	14348	12872	23031	12872	Instantane

(1a) Track at 0.05 °/sec (worst case elevation unbalance)
(1b) Track at 0.05 °/sec (average elevation unbalance)
(2a) Slew in elevation with worst case wind attitude (maximum elevation unbalance) conservative - these loads may cancel out, but we simply add them here
(2b) Slew in elevation with worst case wind attitude (average elevation unbalance) conservative - these loads may cancel out, but we simply add them here
(3) Slew in azimuth at the maximum slew rate under the worst case wind attitude.
(4a) Slew in both axis at maximum slew rate under the worst case combined wind attitude (maximum el conservative - these loads may cancel out, but we simply add them here
(4b) Slew in both axis at maximum slew rate under the worst case combined wind attitude (average elev conservative - these loads may cancel out, but we simply add them here
(5a) Indexer slew (maximum indexer unbalance at maximum elevation angle)

	Azimuth	Elevation	Indexer	Distribution	
Duty cycle Observation:	3%	3%	3%	54%	Relative pointing & tracking
Duty cycle Pointing Calibration:	3%	5%	10%	5%	Pointing Model Calibratoin
Downtime :				5%	Bad weather & maintenance
Combined Wind Direction factor :	0.6				
Acceleration factor :	1.1				

Table 55: DS Power Budget Table

A Beckhoff terminal EL3403 will be used to measure the voltage, power factor, current and frequency of the incoming power lines. The incoming power will be measured via simple current converters in combination with the direct voltage measurement inside the pedestal shielded compartment power distribution box (+PSC-DB).

Figure 291: Power Converter

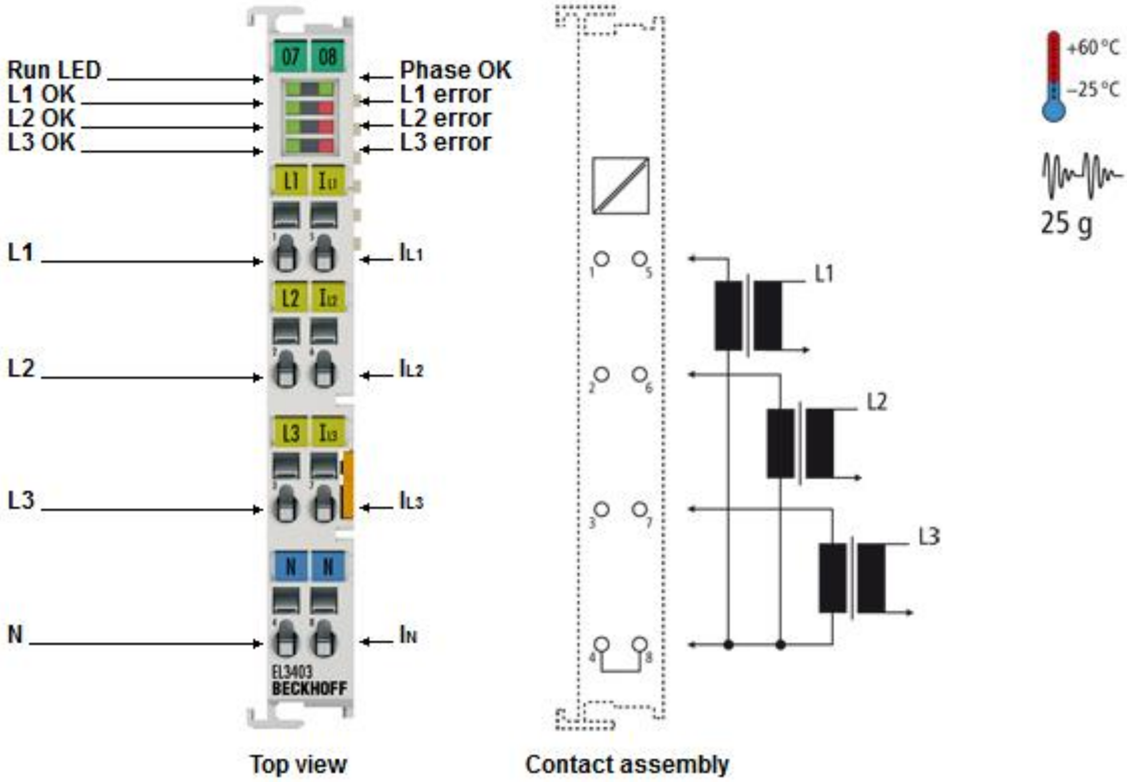


Figure 292: EL3403 Power Measuring Terminal

The EL3403 EtherCAT Terminal enables the measurement of all relevant electrical data of the supply network. The voltage is measured via the direct connection of L1, L2, L3 and N. The current of the three phases L1, L2 and L3 is fed via simple current transformers. All measured currents and voltages are available as root-mean-square values. In the EL3403 version, the effective power and the energy consumption for each phase are calculated. The root-mean-square value of voltage U, current I and the effective power P, apparent power S, reactive power Q, frequency F and phase shift angle cos ϕ can be derived. The EL3403 provides a comprehensive network analysis and an energy management option.

Technical data	EL3403 | ES3403
Number of inputs	3 x current, 3 x voltage
Technology	3-phase power measurement for alternating voltages
Oversampling factor	–
Distributed clocks	–
Resolution	1 µA, 0.1 mV, 10 mW
Conversion time	mains-synchronous
Measured values	current (I1, I2, I3), voltage, effective power, reactive power, apparent power, energy, cos φ, frequency
Measuring voltage	max. 500 V AC 3~ (ULx-N: max. 288 V AC)
Measuring current	max. 1 A (AC), via measuring transformers x A/1 A
Measuring error	0.5 % relative to full scale value (U/I), 1 % calculated value
Measuring procedure	true RMS
Update time	net-synchronous
Electrical isolation	1500 V
Current consumption power contacts	–
Current consumption E-bus	typ. 120 mA
Bit width in the process image	62 byte PM input, 3 byte PM output
Special features	true RMS value calculation, single-phase operation also possible
Weight	approx. 75 g
Operating/storage temperature	-25…+60 °C/-40…+85 °C
Relative humidity	95 %, no condensation
Vibration/shock resistance	conforms to EN 60068-2-6/EN 60068-2-27
EMC immunity/emission	conforms to EN 61000-6-2/EN 61000-6-4
Protect. class/installation pos.	IP 20/variable
Pluggable wiring	for all ESxxxx terminals
Approvals	CE, UL

Figure 293: Technical Data of EL3403

4.7 Remote Support Capabilities

The MTM control system has the capability to remotely connect to the control computer and to login to the real-time operating system to investigate all variables online while the telescope is operating. This intervention does not influence the real-time behaviour, or the performance of the control system.

In addition, real-time data can be logged and plotted over time to follow the behaviour. This logged data can later be exported and used in Matlab for further investigation and analysis (see Figure 294).

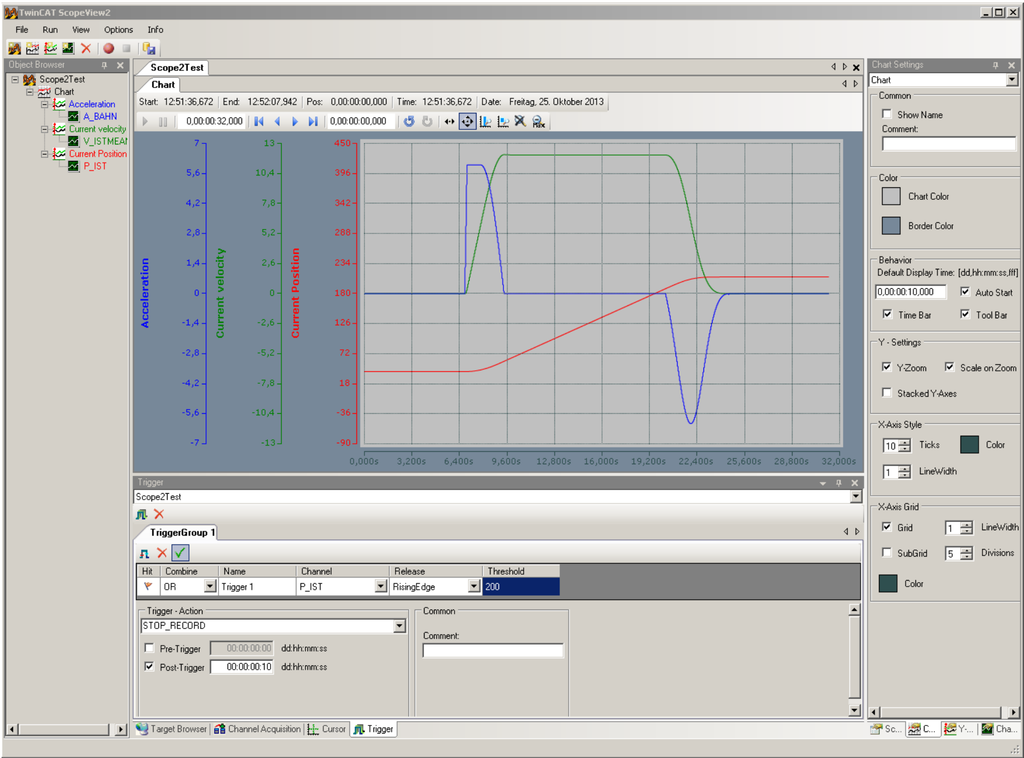


Figure 294: TwinCAT Scope View

4.8 External Interfaces

- *DS interface to the Infrastructure Element: [SKA-TEL-SKO-0000115]*
- *DS interface to the SaDT Element: [SKA-TEL-SADT.SE-TEL.DSH.SE-ICD-001]*
- *DS Data Exchange interface to LMC: [SKA-TEL-DSH-0000053]*
- *DS Physical interface to SPF Receiver: [SKA-TEL-DSH-0000057]*
- *DS Physical interface to SPF Band 1 Feed package: [SKA-TEL-DSH-0000058]*
- *DS Physical interface to SPF Band 2 Feed package: [SKA-TEL-DSH-0000059]*
- *DS Physical interface to SPF Band345 Feed package: [SKA-TEL-DSH-0000060]*
- *DS Physical interface to SPF vacuum system: [SKA-TEL-DSH-0000061]*
- *DS Physical interface to SPF Helium system: [SKA-TEL-DSH-0000062]*
- *DS Physical interface to SPF Controller: [SKA-TEL-DSH-0000063]*
- *DS Physical interface to Dish Fibre Network: [SKA-TEL-DSH-0000068]*
- *SKA1 Mid Dish provision for PAF: [301-000000-017]*

5 SKA Dish Structure RFI Design

5.1 General Description

The scope of the EMI/RFI shielding design of the dish structure can be classified according to the locations of the devices with derived requirements, including pedestal shielding compartment, EMI shielded drive cabinet, EMI shielded cabinet, pedestal & turnhead and the indexer.

The EMI/RFI shielding design of the PSC includes:

- PSC enclosure
- PSC door
- PSC ventilation system
- PSC cable penetrations
- PSC fibre penetrations
- EMI shielded cabinet
- EMI shielded drive cabinet
- Electric devices selection
  - Indoor thermal and humidity sensor
  - Door limit switch
  - Lighting devices

The EMI/RFI shielding design of the DS devices on the pedestal and turnhead includes:

- Azimuth I/O unit assembly
- Elevation I/O unit assembly
- Electric devices selection
  - Azimuth stow motor
  - Tilting meter
  - Warning horn and light
  - Ambient thermal sensor
  - Door limit switch
  - Lighting devices

The EMI/RFI shielding design of the DS devices on the indexer includes:

- indexer I/O unit assembly
- Electric devices selection

The RFI/EMI design is referred to the "SKA1-MID PEDESTAL SHIELDED COMPARTMENT CONCEPT" and "Dsh Emi Control Plan" and the design that has been used on MeerKAT.

5.1.1 SKA DS RFI Shielding Engineering Requirement

The SKA RFI shielding engineering requirement is derived from the following documents:

"SKA-TEL-DSH-0000076 Level 2 and Level 3 SKA1 Dish EMI Requirements GvdM_4"
"SKA-TEL-DSH-0000011 Dish Structures (DS) Requirements Specification"
"Dish Structure EMI Test Procedure Rev01 (2018-06-25) - signed (003)"

The following documents are referenced in this document. In the event of conflict between the contents of the referenced documents and this document, **this document** shall take precedence.

[1] SKA1-MID PEDESTAL SHIELDED COMPARTMENT CONCEPT
[2] 301-000000-011_Rev1 Dsh Emi Control Plan
[3] Dish Structure EMI Test Procedure Rev01 (2018-06-25) - signed (003)

5.2 EMI/RFI shielding design of the PSC

5.2.1 Shielding Effectiveness Budget (PSC)

SKA Requirement:

The DS shall provide EMI shielding, to the components inside the EMI Shielded Cabinet, greater than:

- **160 dB for all frequencies from 50 MHz to 13.8 GHz and**
- **110 dB for all frequencies from 13.8 GHz to 20 GHz**

Allocated Requirements for SKA:

a. EMISC:

The EMISC shall provide EMI shielding greater than:

- **80dB for all frequencies from 50 MHz to 13.8 GHz and**
- **60dB for all frequencies from 13.8 GHz to 20 GHz**

b. Drive Cabinet:

Based on the MeerKAT measurement results:
The drive cabinet shall provide EMI shielding greater than:

- **60dB for all frequencies from 50 MHz to 13.8 GHz and**
- **60dB for all frequencies from 13.8 GHz to 20 GHz**

c. PSC:

The PSC shall provide EMI shielding greater than:

- **80dB for all frequencies from 50 MHz to 13.8 GHz and**
- **50dB for all frequencies from 13.8 GHz to 20 GHz**

5.2.2 PSC enclosure

The PSC walls consist of 20 mm pedestal steel structure and 10mm stainless plates inside the pedestal. The walls are seam welded.

5.2.3 PSC door

The PSC door is the standard dual blade-quad Be-Cu finger stock RFI shielded door. The clear opening of the door is the 700 mm * 2300 mm and outer dimensions are 990 mm * 2550 mm. The PSC door is manually operated and is opened to the inside of the PSC. The door can be operated on both sides. The PSC door is bolted on the PSC wall with conductive gasket.

An emergency rescue window is applied to the PSC door as shown in Figure 295. When the accident occurred to the personnel inside the PSC and the PSC door cannot be opened from the outside, the safety officer and rescuer can pull out the emergency hatch, disconnect the door locking structure easily, remove the decorative sheet in the rear and climb into the PSC. The emergency hatch is applied with EMI shielding features and can be re-used.

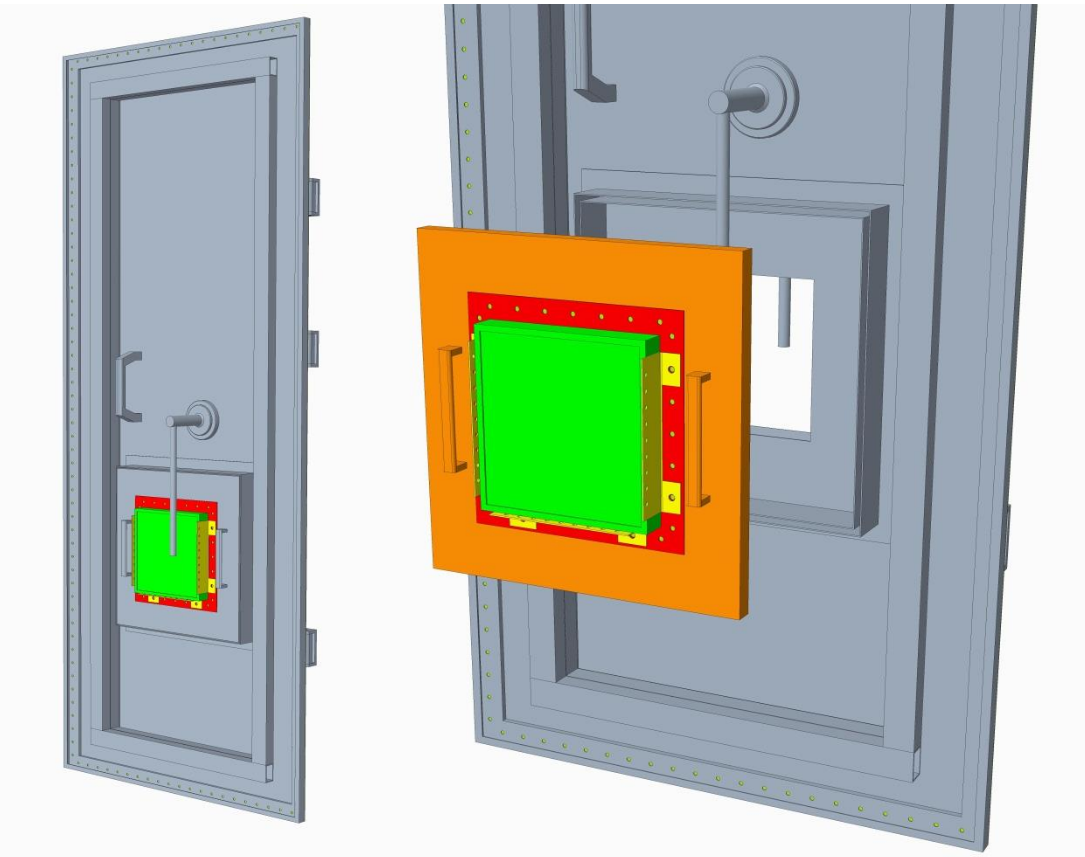


Figure 295: Delivered RFI Shielded Door

5.2.4 PSC Power cable penetrations

The power filters are used where the power cables penetrate through the RFI enclosure, shown in Figure 296. The power filters are mounted on the inner surface of the enclosure by nuts. The conductive gaskets are used between the filters and enclosure surface to ensure the RFI shielding effectiveness.
The power filters are in series with the power cables to interdict the electromagnetic signal on the cables and to restrain the high frequency interference signal.
The high performance differential-mode power filter can achieve 120db of insertion loss within the frequency range from 50 MHz to 20 GHz, which is sufficient for the requirement. The insertion loss is in accordance with the shielding effectiveness so that the filters can prevent the leakage of

electromagnetic radiation, conducted emission of power circuit and the second leakage of radiation.
The metal wall of PSC and the power supply system is able to pass the 1500 volt withstand voltage test. The insulation resistance between power inlet and PSC wall is higher than 2 MΩ as well as between the cables.

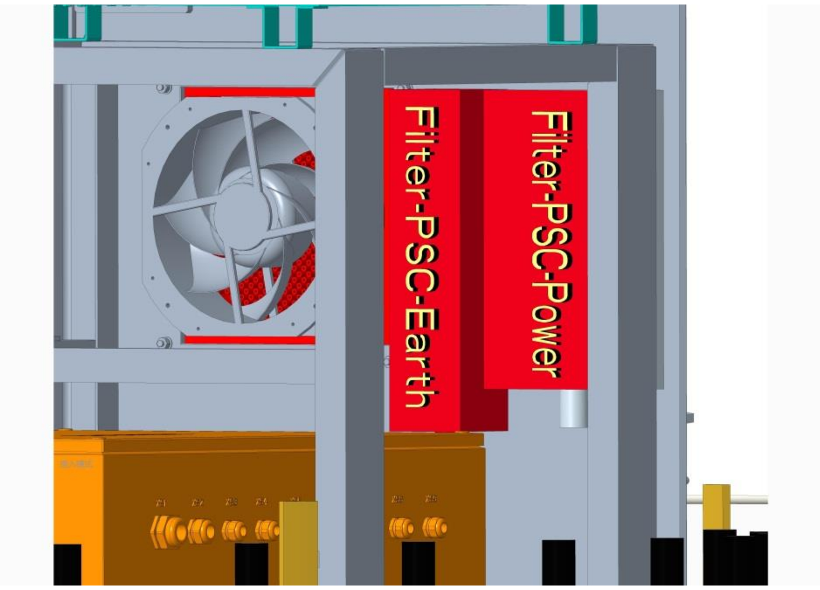


Figure 296: The Power EMI Filters on PSC Inner Wall

5.2.5 PSC Servo Cables Penetrations

The EMI design of servo cable penetrations are based on the EMI shielded drive cabinet. As the drive cabinet can provide sufficient shielding efficiency for its inside components, there is no need to use the PSC to provide the secondary shielding. This could highly reduce the impact of using additional EMI filters on servo performance.
On the other hand, based on the EMI shielding efficiency, the drive cabinet is capable to screen the RFI emission inside the PSC, working as a part of the PSC.
Taken these two points into the consideration, the EMI design of servo cable penetrations uses the metallic cable conduits to connect the servo cabinet output and the PSC penetration points, forming a EMI enclosure. One end of the conduit is connected with the servo cabinet filter with EMI measures, housing the servo cables or fibres. All the conduits are connected with a stainless steel plate with appropriate EMI gland as shown in Figure 297. The plate is to be bolted with the PSC at the ceiling.
The emission on the servo cables has been filtered by the servo cabinet and has been screened from the PSC EMI environment by the metallic conduit.
More information is illustrated in the chapter: “EMI shielding servo cabinet”

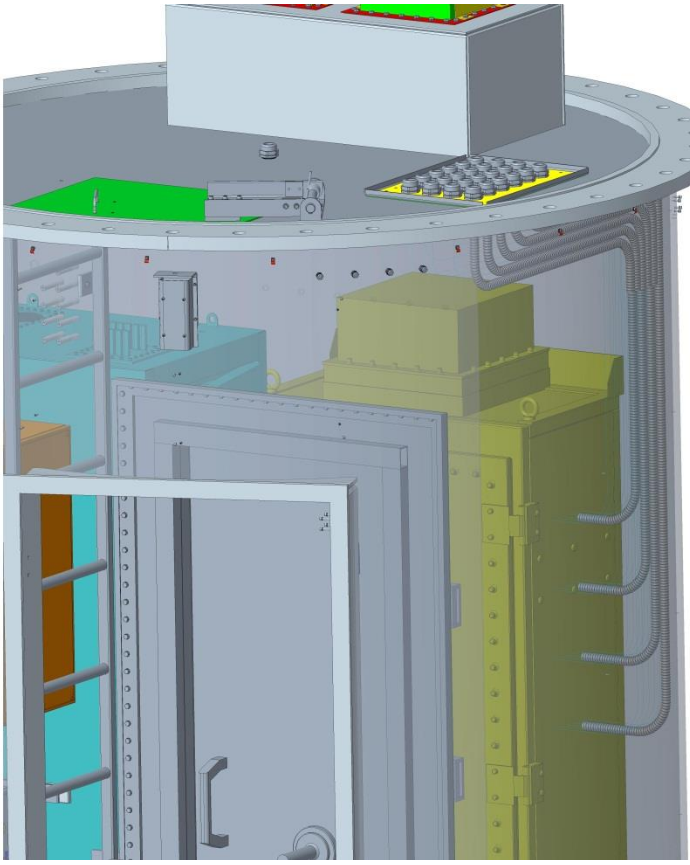


Figure 297: EMI shielding for Servo Cables Inside PSC

5.2.6 PSC Fibre Penetrations

The cut-off wave-guide tube can be used where the fibre cables penetrate through the RFI enclosure. The calculation of wave-guide tube inner diameter is given as followed.

$$\mathrm{f_c} = 17.58 / D$$

Where:

D: diameter of round tube (cm)

$\mathrm{f_c}$: cut off frequency of round tube (GHz)

Thus the derived diameter of round tube is as followed:

$$\mathrm{D} = 17.58 / \mathrm{f_c} = 17.58 / 20 = 0.88\mathrm{cm} = 8.8\mathrm{mm}$$

The diameter of round tube should be less than 8.8mm.

The calculation of wave-guide tube length is given as followed.

$$\mathrm{L} = SE / 8.686 \sqrt{\left(\frac{368.2}{D}\right)^2 - \left(\frac{20\pi \mathrm{f}}{3}\right)^2} = 80 / 8.686 \sqrt{\left(\frac{368.2}{0.52}\right)^2 - \left(\frac{20\pi \times 13.8}{3}\right)^2} = 14.2\mathrm{mm}$$

Where:

SE: shielding effectiveness of wave – guide tube (dB)

f: restrained frequency (GHz)

Based on the calculation above and the diameter of SaDT fibers, 6mm bore diameter wave-guide tube is selected for fibre penetration. The tube is made of stainless steel, which is well welded onto the PSC stainless wall. The length of tube is 100mm. During the EMI shielding efficiency test of PSC, the tubes will be filled with real fibres to represent the practical conditions.

According to the calculation above, given the requirement of shielding effectiveness of PSC, one of the wave-guide configurations is that the bore diameter of wave-guide tube is 6 mm and the length is 20 mm.
In addition, the calculation above is also used to select the wave-guide vent. The bore diameter of single wave-guide tube is 5.2mm and the length of the tube is 20mm.

Based on the diameter of 5.2 mm, the length of 20mm can be checked as followed:

$$\mathrm{L} = SE/8.686\sqrt{\left(\frac{368.2}{D}\right)^2-\left(\frac{20\pi \mathrm{f}}{3}\right)^2} = 80/8.686\sqrt{\left(\frac{368.2}{0.52}\right)^2-\left(\frac{20\pi\times 20}{3}\right)^2} = 10\mathrm{mm}$$

The calculation shows that the wave-guide vent can fulfil the required shielding efficiency.

The fibre cable penetrations are recommended to have spare part for easy maintenance.

5.2.7 PSC ventilation system

The wave-guide vents are used for the ventilation system of the PSC, as shown in Figure 298. The standard dimensions are 300mm*300mm. According to the calculation in the section 5.4.4.6, the circumcircle diameter of single wave-guide hole is 5.2 mm and the depth is 20 mm.
The single layer of wave-guide vent can achieve 80db of RFI shielding effectiveness. The economic wind speed is 3 ~ 4 m/s with ventilation ratio about 70%.
The inlet and outlet wave-guide vents are bolt-mounted with EMI gasket. The vent fans are mounted on the PSC side so that the EM emission can be shielded; even it is foreseen to be negligible.

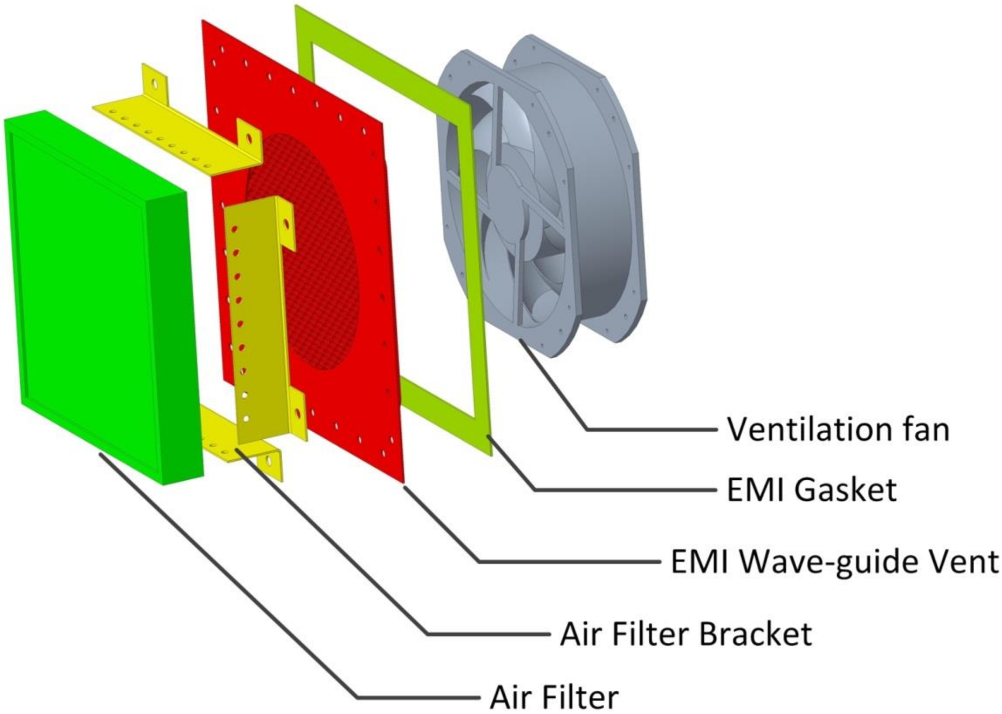


Figure 298: Ventilation EMI design

5.2.8 Lighting devices

The incandescent lamps are applied for the fixed lighting device. The electromagnetic radiation of incandescent lamp is so small that can be negligible and therefore no RFI shielding is necessary.

5.3 EMI/RFI Shielding Design of the Equipment Inside the PSC

5.3.1 EMI Shielding Cabinet

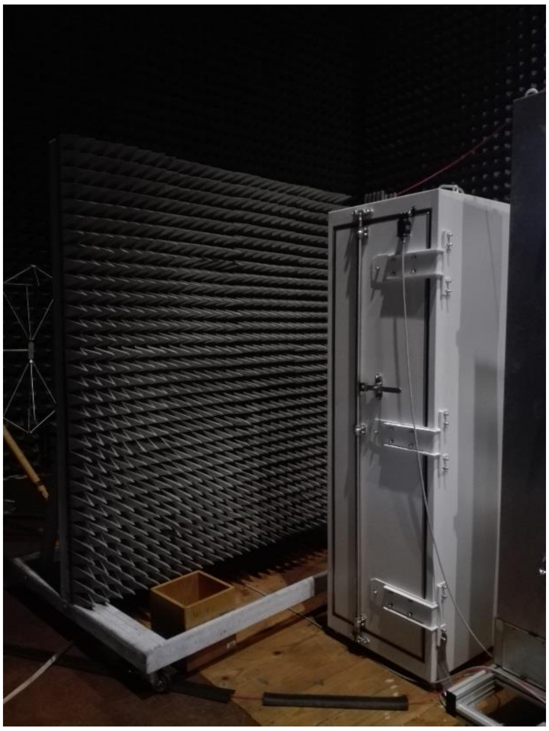


Figure 299: Shows the EMISC as tested in the anechoic chamber

The shielding effectiveness has been tested in the following document: “EMISC test report” attached in the Annex Folder.

5.3.2 EMI Shielding Servo Cabinet

Figure 300 Drive Cabinet:

Figure 300 shows the drive cabinet with EMI Filters in the bottom and at the wall as well as the fibre optic penetrations on top of the wall. Also the honeycomb filters in the door and on the roof of the drive cabinet can be seen as well as the frequency converters inside the DC

The shielding effectiveness has been tested in the following document: “A318010 Test-report”. It can be found in the Annex folder.

The conduits (metal braiding) are connected with the servo cabinet filter with EMI measures, housing the servo cables or fibres. All the conduits are connected with a stainless steel plate inside the PSC roof with appropriate EMI glands.

Figure 301: shows the type of braiding between the DC Filters and the PSC roof feed rough plate

The following Excel Sheet shows the filters and designations used for miscellaneous equipment in the SKA Dish Structure provided by MTM. The Filters are designed and manufactured by Bajog.

Filter-Type:	Number:	
GB.E50.002A.BI.L.01.1.18	1	Feedback Motors
GB.E18.002A.BI.L.01.1.18	2	Temp/Tilt/Warn/StowPin
GB.E18.002A.BI.L.02.1.18	3	JB & HBG
GB.E20.002A.BI.L.03.1.18	4	PED-Chain/PSC-Chain/…
GB.E8.002A.BI.L.01.1.18	5	ELC
GB.E2.003A.BI.L.06.1.18	6	W1310 24VDC
GB.E2.002A.BI.L.09.1.18	7	AZC
GB.E5.014A.BI.L.01.1.18	8	AZ1
GB.E5.014A.BI.L.02.1.18	9	AZ2
GB.E5.018A.BI.L.01.1.18	10	EL
GB.E5.004A.BI.L.01.1.18	11	FI1
GB.E5.004A.BI.L.02.1.18	12	FI2
GB.E3.002A.BI.L.01.1.18	13	StowPin Motor
GB.D4.032A.BI.S.26.1.18	14	W1040 Power
GB.E10.002A.BI.L.02.1.18	16	FIC
GB.E8.002A.BI.L.02.1.18	17	Power Measure W9020

All filter specifications can be seen in the Bajog filter design documents like the following one:

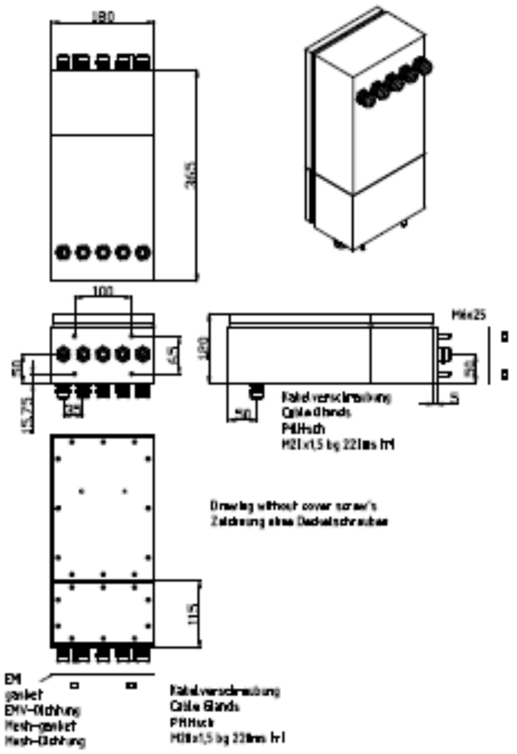
data sheet
Datenblatt

GB.E50.002A.BI.L.01.1.18

Cabin-Filter for Shielded-Rooms,
Kabinenfilter für geschirmte Räume

Motor-Encoder

50 lines
50 polig



Characteristics, advantages
Charakteristika, Vorteile

- very high attenuation
  hohe Dämpfungseigenschaft
- small case dimensions
  kleine Gehäuseabmessung
- high conductive surface, to eliminate case resistance
  hoch leitende Oberfläche, dadurch entstehen keine Übergangswiderstände
- 50 separate lines independent from each other
  50 voneinander unabhängige Phasen
- No saturation effect even of high asymmetrical noise current
  Auch bei großen Asymmetrischen Stör-strömen entsteht kein Sättigungsverhalten
- with 10 x cable fittings manufacturer Pflitsch Type M20 x1,5
  mit 10 x Kabelverschraubungen Hersteller Pflitsch Typ M20 x 1,5
- with EMC-gasket+ Mesh-gasket
  mit EMV-Dichtung + Mesh-Dichtung

Tolerance/Toleranz DIN 7168sg

edition from: A/14.03.18
Ausgabe vom:
und den Änderungsindex

printed: 16.03.2018 10:11
Gedruckt am:

changing-index:
Produkt-Änderungsindex: RP / JO

please check the current update status before an order
Bitte überprüfen Sie vor jeder Bestellung das aktuelle Ausgabedatum

technical changings reserved!
technische Änderungen vorbehalten!

Bajog electronic GmbH ~ Mühlstr. 4 ~ D – 94431 Pilsting ~ phone.: +49 / 9953 / 3002-0 ~ fax: +49 / 9953 / 3002-13 ~ e-mail: info@bajog.de

technical data - Leistungsdaten

GB.E50.002A.BI.L.01.1.18

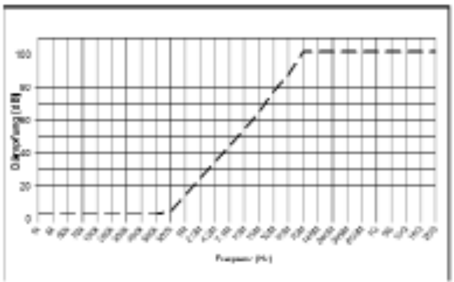
nominal voltage L- L: Nominalspannung L- L:	**100V (DC- AC)**
nominal voltage L- PE: Nominalspannung L- PE:	**100V (DC- AC)**
nominal current: Nominalstrom:	**2A at 100% duty cycle Dauerlast**
DC-resistance: DC-Widerstand:	**< 0,5 Ω**
attenuation range: Dämpfungsbereich:	**10kHz up to/bis 20GHz**
test-voltage L- L: Prüfspannung (L- L):	**500VDC for 2 seconds für 2 Sekunden**
test voltage L- PE: Prüfspannung (L- PE):	**500VDC for 2 seconds für 2 Sekunden**
Tests in reffering to: Tests in Anlehnung:	**EN 60939 part/Teil 1-3 MIL-STD-220C;MIL- STD.810; STANAG 2895; STANAG 4236; MIL-STd 461E**
climatic-class: Klimaklasse:	**HPF (25/085/21)**
Ambient temperature : Umgebungstemperatur:	**-10°C to/bis +65°C**
terminal: Anschlußart:	**Load: Klemmen/clamps push-in-Anschluss Line: Wire 5x(4(2x0,14)+(2x1,0)) 3,5m**
dimensions (WxHxL): Gehäusemaße (BxHxL):	**180 x 120 x 365mm**
weight: Gewicht:	**approx./ca. 20 kg**

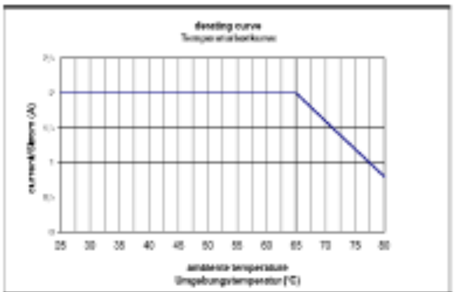
insertion loss at 50Ω

Einfügungsdämpfungskurve an 50Ω

____ differential mode ____ symmetrisch

_ _ _ _ common mode _ _ _ _ asymmetrisch

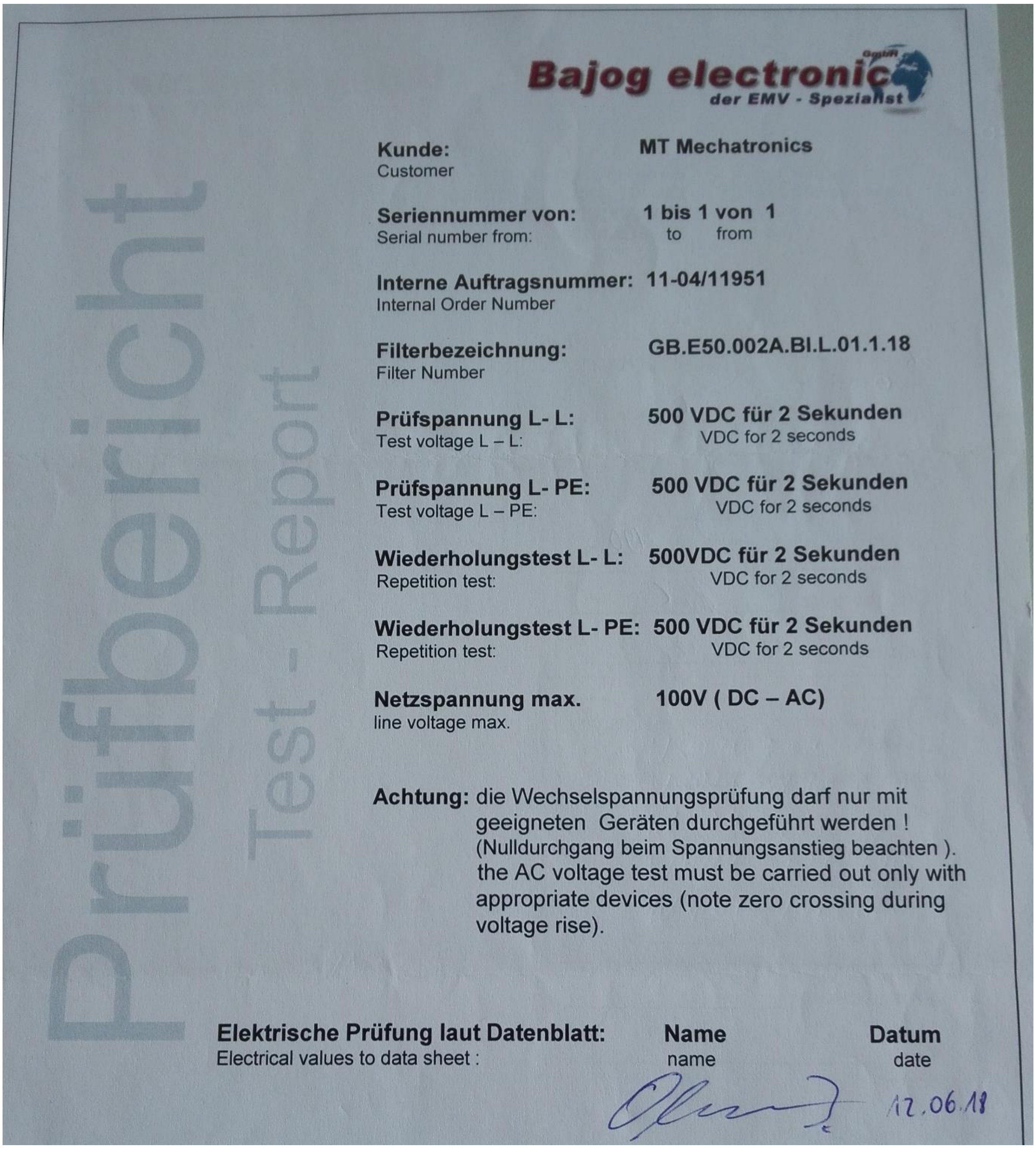




Please note that the standards mentioned in our datasheets (EN, MIL-Std) are referred to due to reasons related to the filter development and assembling at Bajog electronic.
If an additional certificate for a single filter tested under load is desired, an order apart will be required. The costs for such particular test will be quoted and invoiced separately. The tests will be conducted by an independent testing laboratory according to technical feasibility.
If no specific test in line with the above-mentioned additional standards is commissioned, the manufacturer will not be required to submit the ordered filters to an independent testing laboratory for individual tests or additional componentry tests.

Wir weisen darauf hin, dass die im Datenblatt aufgeführten Normen (EN, MIL-Std,) zur Entwicklungs- u. Fertigungsgrundlage bei Bajog electronic herangezogen werden.
Wenn ein zusätzlicher Prüfungs- u. Einzelnachweis gemäß einer dieser Normen für ein Filter unter Last gewünscht wird, ist hierzu eine gesonderte Beauftragung durch den Kunden erforderlich. Die Kosten für die Einzel – Nachweisprüfung werden von Bajog electronic gesondert angeboten und in Rechnung gestellt. Die Prüfungen selbst werden dann von einem unabhängigen Prüflabor je nach technischer Möglichkeit durchgeführt.
Wenn keine gesonderte Einzelprüfung im Rahmen der Zusatznormen als Auftrag an Bajog electronic erteilt wird, besteht auch keine Verpflichtung seitens des Herstellers, die bestellten Filter einer Einzelprüfung oder einer zusätzlichen Baugruppenprüfung durch ein unabhängiges Prüflabor zu unterziehen.

Bajog electronic GmbH ~ Mühlstr. 4 ~ D – 94431 Pilsting ~ phone.: +49 / 9953 / 3002-0 ~ fax: +49 / 9953 / 3002-13 ~ e-mail: info@bajog.de



Prüfbericht
Test - Report

Bajog electronic GmbH
der EMV - Spezialist

Kunde: Customer	**MT Mechatronics**
Seriennummer von: Serial number from:	**1 bis 1 von 1** to from
Interne Auftragsnummer: Internal Order Number	**11-04/11951**
Filterbezeichnung: Filter Number	**GB.E50.002A.BI.L.01.1.18**
Prüfspannung L- L: Test voltage L – L:	**500 VDC für 2 Sekunden** VDC for 2 seconds
Prüfspannung L- PE: Test voltage L – PE:	**500 VDC für 2 Sekunden** VDC for 2 seconds
Wiederholungstest L- L: Repetition test:	**500VDC für 2 Sekunden** VDC for 2 seconds
Wiederholungstest L- PE: Repetition test:	**500 VDC für 2 Sekunden** VDC for 2 seconds
Netzspannung max. line voltage max.	**100V (DC – AC)**

Achtung: die Wechselspannungsprüfung darf nur mit geeigneten Geräten durchgeführt werden ! (Nulldurchgang beim Spannungsanstieg beachten). the AC voltage test must be carried out only with appropriate devices (note zero crossing during voltage rise).

Elektrische Prüfung laut Datenblatt: Electrical values to data sheet :	**Name** name	**Datum** date
	Olm	12.06.18

The filters have the following features:

- **Very high attenuation**
- **Small case dimensions**
- **High conductive surface, to eliminate case resistance**
- **Separate lines independent from each other**
- **No saturation effect even at high asymmetrical noise currents**
- **Delivered with with cable gland Pflitsch bluglobe TRI**
- **Delivered with EMC-gasket + Mesh-gasket**

The following pictures show the typical designed transmission curve as well as the typical derating curve design of the Bajog filters:

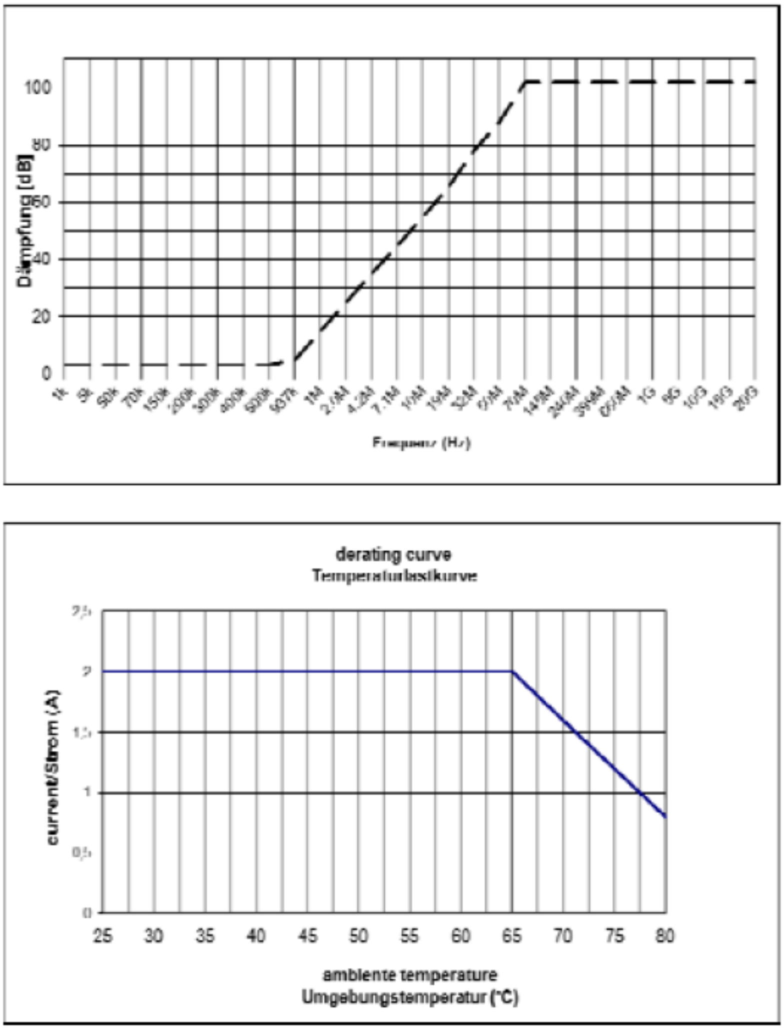


Figure 302: Showing transmission curve and derating curve of a Bajog filter

All the data sheets can be found in the Annex folder as well as the excel sheet for the filter design and a pdf blockdiagram including the filter numbers. Filename of the Excel sheet is “SKA_Cable_Filter_20180926_MEC_Assignment Filter”. Filename of the blockdiagram including filternumbers is “SKA_Blockdiagram_20171127 including FilterNo”.

5.4 EMI/RFI Shielding Design of the Equipment inside the Tower

5.4.1 Azimuth I/O unit

Figure 303: Showing the Azimuth IO-Unit with EMI Filter mounted and the sealed shaft

The I/O unit assembly consists of encoder, limit switch, temperature & humidity sensor, I/O unit, filters and RFI enclosure. The locations of I/O units are inside the upper section of pedestal and outside the turn-head and indexer.

The RFI enclosure is to prevent the electromagnetic emission of inner devices to the outer environment. It also provide mounting interface for I/O unit, sensors, 24V power filters and fibre wave-guide tube. The RFI enclosure is made of stainless steel and is bolt-mounted on the flange. There is a bolted lid on the enclosure for installation, alignment and maintenance. All interfaces shall be sealed by gasket. The environmental protection shall be produced for the elevation and indexer I/O units by using the sealant.

The shaft of the encoder is shielded by using double BALSEAL EMI spring seals, which is similar to the design applied on MeerKAT dishes. The housing of the spring seal is made of stainless steel and is bolted on the bracket with conductive gasket. There shall be double slots on the matching surface of housing, where the spring seals can be installed.

The EMI spring seal is supplied by BALSEAL. The seal is made of copper alloy and is nickel-plated for high conductivity. The spring seal is custom designed to achieve low friction less than 0.5N so that there may not be any impact on the encoder performance and accuracy.

5.5 EMI/RFI shielding design of the equipment outside the tower/at the turnhead

5.5.1 Elevation I/O unit

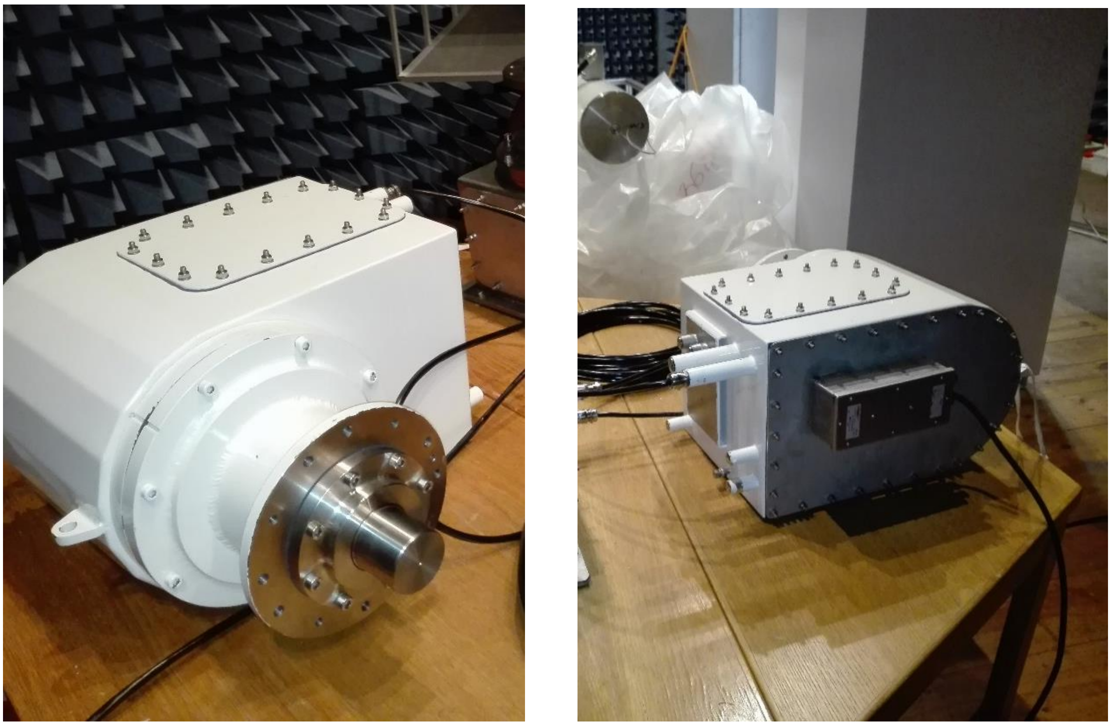


Figure 304: Showing the Elevation IO-Unit with EMI Filter and waveguide penetrations as well as the environmentally protected fibre cable and the sealed shaft

5.5.2 Tilt meter

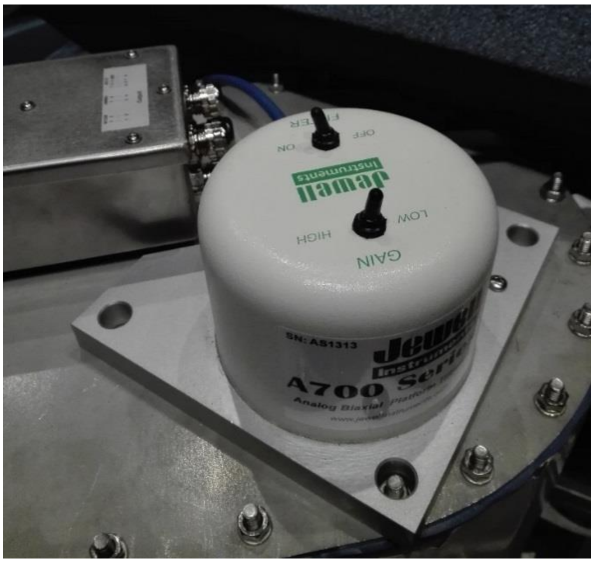


Figure 305: Showing the tilt meter

5.5.3 Indexer I/O unit

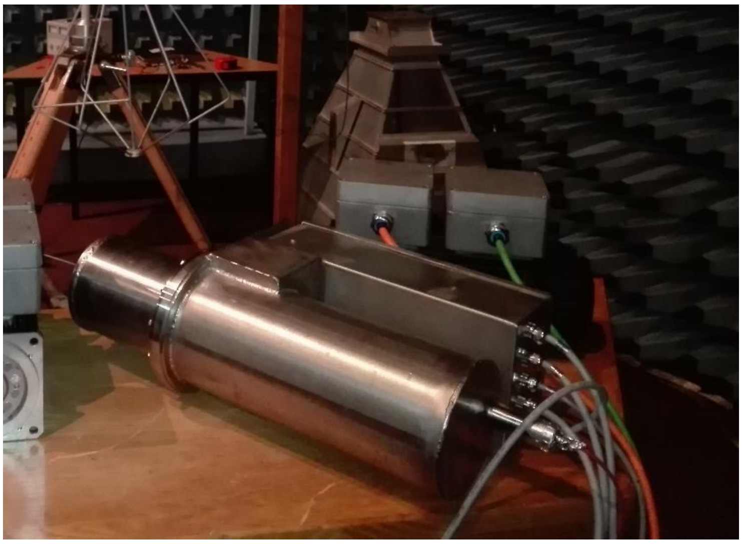


Figure 306: Shows the Feed Indexer as well as the filter and the waveguide fibre penetration

The RFI/EMI design is referred to the "SKA1-MID PEDESTAL SHIELDED COMPARTMENT CONCEPT" and "Dsh Emi Control Plan" and the design that has been used on MeerKAT.
The test procedure for the actual equipment is documented in "Dish Structure EMI Test Procedure Rev01 (2018-06-25) - signed (003)"

5.5.4 Warning horn and light

Figure 307: Warning horn (top) and warning light (bottom)

The electronics for the warning horn and the warning light are inside a shielded enclosure.

6 Appendix

6.1 Appendix: Sensitivity Analysis - Feed Indexer & Subreflector Deflections

This section describes the analysis results of the effects of the feed indexer and subreflector deflection on dish performance, including aperture efficiency and pointing error and error beam. All simulations are carried out in GRASP, using Physical Optics (PO) and Physical Theory of Diffraction (PTD).

Figure 308 shows the coordinate system of the dish, the coordinate of the dish is defined as (X, Y, Z), the coordinate of the feed is defined as (X_f, Y_f, Z_f), and the coordinate of the feed is defined as (X_s, Y_s, Z_s). The simulation was carried out at 20 GHz, and the GRASP model is shown in Figure 309.

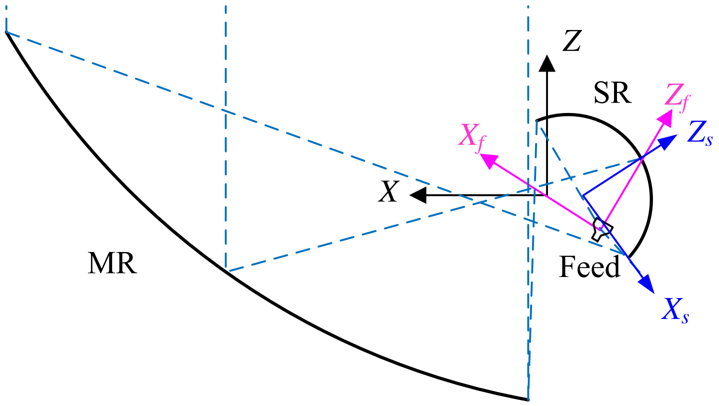


Figure 308: Coordinate of the Dish

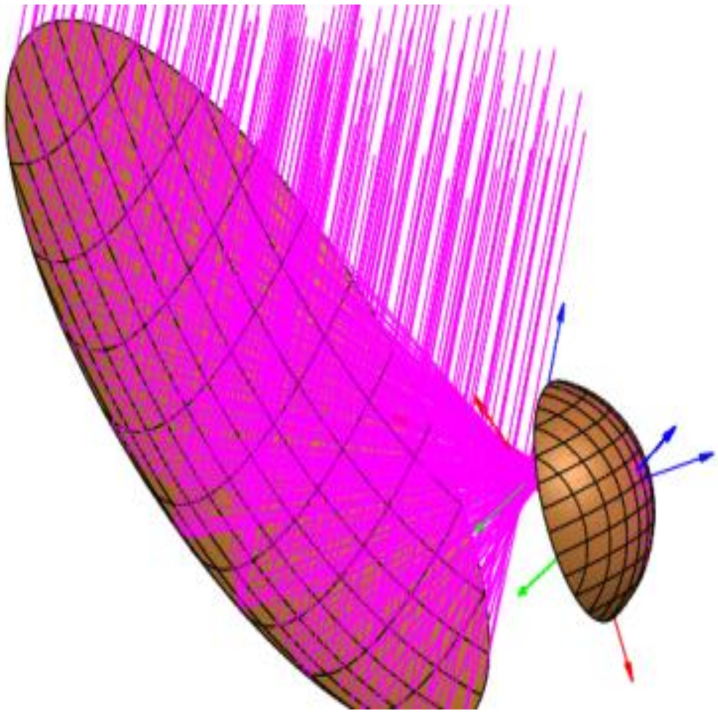


Figure 309: Simulation Model in GRASP

6.1.1 Effects of the Feed Indexer Deflection on Dish Performance

The indexer provides the function of frequency band switching, which sets a criteria on position repeatability. The repeat position error leads to a random error which cannot be calibrated. The feed indexer deflection can be treated as off-focus feed, including the displacement along X_f, Y_f, and Z_f axes, and rotation along Y_f axis (θ_f) and X_f axis (Φ_f). Table 56 ~ Table 61 present the simulation results. The aperture efficiency and pointing error are calculated at 20 GHz, while the error beam is calculated at 13.8 GHz.

Table 56: Dish Performance at the Feed Displacement along X_f Axis

Displacement /mm	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-5	99.95	108.54	0.56
-3	99.99	65.34	0.39
-1	100.01	21.6	0.08
-0.5	100.00	10.8	0.04
-0.2	100.00	4.53	0.02
-0.1	100.00	2.04	0.01
0	100.00	0	0.00
0.1	100.00	2.02	0.01
0.2	100.00	4.53	0.02
0.5	99.99	10.8	0.04
1	99.99	21.6	0.08
3	99.93	65.34	0.35
5	99.85	109.08	0.62

Table 57: Dish Performance at the Feed Displacement along Y_f Axis

Displacement /mm	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-5	99.92	106.93	0.58
-3	99.97	63.20	0.27
-1	100.00	20.04	0.09
-0.5	100.00	9.30	0.04
-0.2	100.00	2.99	0.02
-0.1	100.00	1.08	0.01
0	100.00	0.00	0.00
0.1	100.00	1.08	0.01
0.2	100.00	2.99	0.02
0.5	100.00	9.30	0.04
1	100.00	20.04	0.09
3	99.97	63.20	0.27
5	99.92	106.93	0.58

Table 58: Dish Performance at the Feed Displacement along Z_f Axis

Displacement	Relative efficiency	Pointing error	Error beam

/mm	/%	/arcsec	/%
-5	100.98	0.00	1.43
-3	101.33	0.00	0.97
-1	100.69	0.00	0.36
-0.5	100.37	0.00	0.19
-0.2	100.16	0.00	0.08
-0.1	100.08	0.00	0.04
0	100.00	0.00	0.00
0.1	99.92	0.00	0.04
0.2	99.83	0.00	0.08
0.5	99.57	0.00	0.20
1	99.07	0.00	0.41
3	96.53	0.00	1.35
5	93.12	0.00	2.47

Table 59: Dish Performance at the Feed Rotation in ϑ_f

Displacement /Deg	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-2	99.87	0.17	0.10
-1	99.98	0.09	0.05
-0.5	100.00	0.08	0.03
0	100.00	0	0.00
0.5	99.98	0.09	0.03
1	99.93	0.1	0.06
2	99.78	0.15	0.12

Table 60: Dish Performance at the Feed Rotation in Φ_f

Displacement /Deg	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-2	99.83	1.17	0.32
-1	99.96	0.67	0.12
-0.5	99.99	0.22	0.06
0	100.00	0.00	0.00
0.5	99.99	0.22	0.06
1	99.96	0.67	0.12
2	99.83	1.17	0.32

Following results show the effects on the dish performance of feed displacement from the focus within the sphere of radius 0.1 mm.

Table 61: Dish Performance at the Feed Displacement at Worst Cases

Displacement /mm	Relative efficiency /%	Pointing error /arcsec	Error beam /%
X_f=0.07mm, Y_f=0.07mm, Z_f=0.05mm, θ_f=1Deg, Φ_f=1Deg	99.89	0.00	0.12
X_f=-0.07mm, Y_f=0.07mm, Z_f=0.05mm, θ_f=1Deg,	99.89	2.00	0.09

Φ_f=1Deg			
X_f=0.07mm, Y_f=0.07mm, Z_f=0.05mm, θ_f=-1Deg, $\Phi=_f$1Deg	99.94	0.00	0.06
X_f=-0.07mm, Y_f=0.07mm, Z_f=0.05mm, θ_f=-1Deg, Φ_f=1Deg	99.94	2.00	0.10
X_f=0.07mm, Y_f=0.07mm, Z_f=0.05mm, θ_f=1Deg, Φ_f=-1Deg	99.89	0.00	0.11
X_f=-0.07mm, Y_f=0.07mm, Z_f=0.05mm, θ_f=1Deg, Φ_f=-1Deg	99.89	2.00	0.08
X_f=0.07mm, Y_f=0.07mm, Z_f=0.05mm, θ_f=-1Deg, Φ_f=-1Deg	99.94	0.00	0.07
X_f=-0.07mm, Y_f=0.07mm, Z_f=0.05mm, θ_f=-1Deg, Φ_f=-1Deg	99.94	2.00	0.11

From above results, it can be seen the pointing error is the key characteristic which sets the limits. To achieve a two arcsec pointing error, a repeatable accuracy of 0.1mm displacement and 1Deg rotation should be guaranteed. However, there is still a margin in error beam, so the error in installation can be limited in a sphere of 3mm radius relative to the theoretical position.

6.1.2 Effects of the Subreflector Deflection on Dish Performance

There is no mechanism to adjust the position of the subreflector over the full elevation range during operation. Thus, the subreflector deflection is most caused by installation accuracy, environmental and gravity loads. The bulk of pointing error, which is from installation error and gravity deformation, can be calibrated. However, their effect on aperture efficiency and error beam cannot be compensated. The sub-reflector deflection can be decomposed as the displacement along the X_s, Y_s, and Z_s axes, and rotation along the Y_s axis (θ_s), X_s axis (Φ_s), and Z_s axis (Ψ_s). The results are shown in Table 62 ~ Table 68.

Table 62: Dish Performance with the Feed Displaced along X_s Axis

Displacement /mm	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-5	101.96615	202.5	1.22
-3	101.50	121.5	0.87
-1	100.61	40.5	0.34
-0.5	100.32	20.52	0.17
-0.2	100.13	8.1	0.07
-0.1	100.07	4.32	0.12
0	100.00	0	0.00
0.1	99.93	3.78	0.12
0.2	99.87	8.1	0.07
0.5	99.66	20.52	0.18
1	99.29	40.5	0.39
3	97.57	122.04	1.30
5	95.467498	203.58	2.42

Table 63: Dish Performance with the Feed Displaced along Y_s Axis

Displacement /mm	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-5	98.89	211.14	1.28
-3	99.60	125.83	0.73
-1	99.95	41.07	0.24
-0.5	99.99	19.50	0.09
-0.2	100.00	7.17	0.07
-0.1	100.00	2.99	0.04
0	100.00	0.00	0.00
0.1	100.00	2.99	0.04
0.2	100.00	7.17	0.07
0.5	99.99	19.50	0.09
1	99.96	41.07	0.24
3	99.60	125.83	0.73
5	98.90	210.60	1.28

Table 64: Dish Performance with the Feed Displaced along Z_s Axis

Displacement /mm	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-5	85.70	31.86	4.78

-3	93.09	19.44	2.46
-1	98.32	6.48	0.70
-0.5	99.24	3.24	0.33
-0.2	99.72	1.08	0.13
-0.1	99.86	0.54	0.06
0	100.00	0.00	0.00
0.1	100.13	0.54	0.06
0.2	100.25	1.08	0.13
0.5	100.59	3.24	0.30
1	101.00	4.86	0.58
3	100.91	16.20	1.42
5	98.05	29.16	2.55

Table 65: Dish Performance at the Feed Rotation in ϑ_s

Displacement /Deg	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-0.5	87.90	300.24	4.51
-0.4	91.34	239.76	3.98
-0.2	96.81	118.26	1.71
-0.1	98.71	57.78	0.87
0	100.00	0	0.00
0.1	100.65	60.48	0.78
0.2	100.65	120.96	1.74
0.4	98.73	241.38	4.16
0.5	96.89	300.78	4.70

Table 66: Dish Performance at the Feed Rotation in Φ_s

Displacement /Deg	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-0.5	91.66	233.82	6.37
-0.4	94.53	187.38	4.78
-0.2	98.59	93.43	2.11
-0.1	99.65	45.93	1.00
0	100.00	0.00	0.00
0.1	99.64	45.93	1.00
0.2	98.58	93.43	2.11
0.4	94.52	187.38	4.78
0.5	91.65	233.82	6.37

Table 67: Dish Performance at the Feed Rotation in Ψ_s

Displacement /Deg	Relative efficiency /%	Pointing error /arcsec	Error beam /%
-0.5	97.77	1.08	1.96
-0.4	98.57	0.67	1.50
-0.2	99.64	0.33	0.62
-0.1	99.91	0.09	0.29
0	100.00	0.00	0.00
0.1	99.91	0.09	0.29
0.2	99.64	0.33	0.62
0.4	98.58	0.67	1.50
0.5	97.79	1.08	1.95

Table 68: Dish Performance at the Subreflector Displacement at Worst Cases

Displacement	Relative efficiency /%	Pointing error /arcsec	Error beam /%
X_s=0.5mm, Y_s=0.5mm, Z_s=0.7mm, θ_s=0.05Deg, Φ_s=0.05Deg, Ψ_s=0.05Deg	100.91	21.74	0.62
X_s=-0.5mm, Y_s=0.5mm, Z_s=0.7mm, θ_s=0.05Deg, Φ_s=0.05Deg, Ψ_s=0.05Deg	101.39	50.50	0.87
X_s=0.5mm, Y_s=0.5mm, Z_s=0.7mm, θ_s=-0.05Deg, Φ_s=-0.05Deg, Ψ_s=-0.05Deg	99.81	59.16	0.68
X_s=-0.5mm, Y_s=0.5mm, Z_s=0.7mm, θ_s=-0.05Deg, Φ_s=-0.05Deg, Ψ_s=-0.05Deg	100.49	26.06	0.54

Since the pointing error can be largely calibrated, the error beam becomes the most sensitive characteristic to sub reflector deflection. When the sub reflector is kept in a sphere of 1mm radius relative to the theoretical position, with 0.05Deg rotation along three axes, the beam error can be well controlled below 1.0%.

6.2 Appendix: Pointing Error Budget

6.2.1 Contributors and Allocated Values

Different contributors were identified and are listed in Table 69.

- Each contributor has an ID number.
- Allocated values for the contributors have different distributions such as a "peak" value or a "rms" value.
- The contributors are added either systematic or randomly depending on the type. Adding is also differently for calculating the "error circle" or "rms" performance. Refer to TBD for adding logic
- The source values for the steady state environmental effects are output from static finite element analysis (FEA). This includes load cases for ambient (soaked) temperature, thermal gradients over the structure, gravity load and wind loads from different orientations.
- The source values for the dynamic wind effects are output from dynamic End to End analysis (E2E). This includes frequency domain analysis of servo system as well as structural dynamics.
- The source values for Mechanical and Control System errors are either from experience or from datasheets of COTS items.
- Contributors from outside Dish Structure are either defined in Interface Document (ICD) or the DS specification.
- The impact of the contributors is compensated by different methods based on the specific pointing requirement type such as blind Pointing Model (bPM), including metrology, or by Relative Pointing Offset calibration (rPO). The values for the level of compensation are based on experience and predictions together with the static/dynamic type of the specific contributor.

Table 69: Pointing Error Budget Contributors

	Source and Type of Error	#	Error distribution	Summation method			Source values			Compensation	
				r=random s=systematic	error circle	RMS	azimuth / xelev	elevation	source	% removed by blind pointing model	% removed by reference pointing
Environmental Influences (steady state)										**bPM**	**rPO**
	Gravity Deformations	a1	peak	r	x2/3	x1/3	0.00″	31.56″	FEA	95%	92%
0.2	Thermal Deformation (dT Ambient 20K)	a2	peak	r	x2/3	x1/3	0.00″	2.53″	FEA	90%	92%
0.2	Thermal Deformation (dT=5K x-direction)	a3	peak	s1	x2/3	x1/3	0.50″	0.90″	FEA	0%	92%
0.2	Thermal Deformation (dT=5K y-direction)	a4	peak	s1	x2/3	x1/3	0.00″	1.30″	FEA	0%	92%
0.2	Thermal Deformation (dT=5K z-direction)	a5	peak	s1	x2/3	x1/3	0.00″	0.30″	FEA	0%	92%
	Thermal Deformation Pedestal (dT=8K diagonal direction)	a6	peak	s1	x2/3	x1/3	79.20″	79.20″	FEA	95%	92%
	Wind Deformations with static wind - Dish	a7	peak	s2	x2/3	-	-	-	FEA	-	90%
		a8	rms	r	-	x1	-	-	FEA	-	90%
	Wind Deformations with static wind - Foundation	a9	peak	s2	x2/3	-	-	-	FEA (ICD)	-	90%
		a10	rms	r	-	x1	-	-	FEA (ICD)	-	90%
	Wind Deformation - Feeds	a11	peak	r	x2/3	x1/3	-	-	Spec	0%	90%
Environmental Influences (dynamic)											
	Wind gusts on Servo	b1	peak rms	s2	x1	-	-	-	E2E	-	-
		b2	rms	r	-	x1	-	-	E2E	-	-
	Wind gusts on Structure	b3	peak rms	s2	x1	-	-	-	E2E	-	-
		b4	rms	r	-	x1	-	-	E2E	-	-
Mechanical											
	AZ Axis Missalignment NS/EW	c1	peak	r	x2/3	x1/3	15.00″	15.00″	Experience	95%	92%
	Orthogonality AZ/EL-axis	c2	peak	r	x2/3	x1/3	15.00″	15.00″	Experience	95%	92%
	AZ Bearing Run out Axial (wobble)	c3	peak	r	x2/3	x1/3	2.50″	2.50″	Experience	95%	92%
	AZ/EL-Pos. Encoder Offset	c4	peak	r	x2/3	x1/3	9.00″	9.00″	Experience	99%	92%
	EL-Bearing Run out Radial (wobble)	c5	peak	r	x2/3	x1/3	3.00″	0.00″	Experience	95%	92%
	Sub Reflector Collimation accuracy	c6	peak	r	x2/3	x1/3	25.00″	25.00″	Experience	95%	92%
	Feed Indexer Collimation accuracy	c7	peak	r	x2/3	x1/3	25.00″	25.00″	Experience	95%	92%
	Feed Indexer Stability once indexed	c8	peak	r	x2/3	x1/3	1.90″	0.60″	Experience	0%	0%
	Feed indexer positioning accuracy	c9	peak	r	x2/3	x1/3	0.61″	0.00″	Experience	0%	0%
Servo System											
	Control										
	Velocity lag	d1	peak	r	x2/3	x1/3	0.10″	0.10″	Experience	0%	0%
	Acceleration lag	d2	peak	r	x2/3	x1/3	0.10″	0.10″	Experience	0%	0%
	Program Track Interpolation	d3	peak	r	x2/3	x1/3	0.05″	0.05″	Experience	0%	0%
	Time Synchronisation	d4	peak	r	x2/3	x1/3	0.05″	0.05″	Experience	0%	0%
	Tiltmeter accuracy / noise	d5	peak	r	x2/3	x1/3	0.34″	0.34″	Datasheet	90%	92%
	Drive										
	Backlash of drive units	d6	peak	r	x2/3	x1/3	0.02″	0.00″	Experience	0%	0%
	Bearing and Gear Train Friction	d7	peak	r	x2/3	x1/3	0.25″	0.25″	Experience	0%	0%
	Friction variation	d8	peak	r	x2/3	x1/3	0.25″	0.25″	Experience	0%	0%
	Servo loop limit cycle (Friction)	d9	peak	r	x2/3	x1/3	0.50″	0.38″	Experience	0%	0%
	Servo offset and noise	d10	peak	r	x2/3	x1/3	0.30″	0.23″	Experience	0%	0%
	Motor cogging	d11	peak	r	x2/3	x1/3	0.25″	0.25″	Experience	0%	0%
	Encoder										
	Encoder Precision RCN829	d12	peak	r	x2/3	x1/3	1.00″	1.00″	Datasheet	95%	0%
	Encoder coupling	d13	peak	r	x2/3	x1/3	2.50″	1.50″	Experience	95%	92%
	Encoder calibration (can be calibrated)	d14	peak	r	x2/3	x1/3	0.20″	0.20″	Datasheet	95%	92%

6.2.2 Adding of Errors

The different errors are added in a Root Sum Square (RSS) fashion, taking into account the correlated nature of some errors. Refer to Table 70 for detail information.

Table 70: Adding of the Errors

Type	Error Circle	RMS
Gravity & Environment (steady state)	$T1 = ((a1)^2 + (a2)^2 + (a3 + a4 + a5 + a6)^2 + (a11)^2)^{0.5}$	
Environment (dynamic) and Wind (steady state)	$T2 = \frac{2}{3} (\text{abs}(a7 + a9)) + 2 (b1 + b3)$	$T2 = \text{abs}(a8 + a10) + (b2 + b4)$
Mechanical	$T3 = ((c1)^2 + (c2)^2 + (c3)^2 + (c4)^2 + (c5)^2 + (c6)^2 + (c7)^2 + (c8)^2 + (c9)^2)^{0.5}$	
Servo System	$T4 = ((d1)^2 + (d2)^2 + (d3)^2 + (d4)^2 + (d5)^2 + (d6)^2 + (d7)^2 + (d8)^2 + (d9)^2 + (d10)^2 + (d11)^2 + (d12)^2 + (d13)^2 + (d14)^2)^{0.5}$	
Total per Axis	$PEC_{xel,el} = (\frac{2}{3} (T1)^2 + (T2)^2 + \frac{2}{3} (T3)^2 + \frac{2}{3} (T4)^2)^{0.5}$	$RMS_{xel,el} = (\frac{1}{3} (T1)^2 + (T2)^2 + \frac{1}{3} (T3)^2 + \frac{1}{3} (T4)^2)^{0.5}$
Total	$\text{Total PEC} = 2 \times ((PEC_{xel})^2 + (PEC_{el})^2)^{0.5}$	$\text{Total RMS} = ((RMS_{xel})^2 + (RMS_{el})^2)^{0.5}$

6.2.3 Load Cases

The following different load cases are included in the budget. These are combined together simultaneously which will give a slightly conservative performance prediction.

- gravity
- ambient temperature (soaked)
- thermal gradient on structure
- wind loads at different elevation angles and wind directions

For the error circle requirements the worst case elevation angle / wind direction load case is applied. For the "RMS" requirements the root mean square value of all the elevation angle / wind direction load case is applied.

6.2.4 Detail Results

A section of the Budget spreadsheet is shown in Table 71. It also includes elevation angles up to 85° in steps of 15°.

Table 71: Example of Detail Pointing Budget Sheet

Precision Operating Conditions									POC		@ El = 15°							
			Summation method			Source values			Compensation		Cross Elevation Axis				Elevation Axis			
Source and Type of Error	#	Error distribution	r=random s=systematic	error circle	RMS	azimuth / xelev	elevation	source	% removed by blind pointing model	% removed by reference pointing	initial raw error	residual blind pointing error	residual reference/ relative pointing error	tracking stability after relative pointing	initial raw error	residual blind pointing error	residual reference/ relative pointing error	tracking stability after relative pointing
Environmental Influences (steady state)									bPM	rPO								
Gravity Deformations	a1	peak	r	x2/3	x1/3	0.00″	31.56″	FEA	95%	92%	0.00″	0.00″	0.00″	0.00″	31.56″	1.58″	0.13″	0.13″
0.2 Thermal Deformation (dT Ambient 20K)	a2	peak	r	x2/3	x1/3	0.00″	2.53″	FEA	90%	92%	0.00″	0.00″	0.00″	0.00″	2.53″	0.25″	0.02″	0.05″
0.2 Thermal Deformation (dT=5K x-direction)	a3	peak	s1	x2/3	x1/3	0.50″	0.90″	FEA	0%	92%	0.50″	0.50″	0.04″	0.11″	0.90″	0.90″	0.07″	0.19″
0.2 Thermal Deformation (dT=5K y-direction)	a4	peak	s1	x2/3	x1/3	0.00″	1.30″	FEA	0%	92%	0.00″	0.00″	0.00″	0.00″	1.30″	1.30″	0.10″	0.28″
0.2 Thermal Deformation (dT=5K z-direction)	a5	peak	s1	x2/3	x1/3	0.00″	0.30″	FEA	0%	92%	0.00″	0.00″	0.00″	0.00″	0.30″	0.30″	0.02″	0.06″
Thermal Deformation Pedestal (dT=8K diagonal direction)	a6	peak	s1	x2/3	x1/3	79.20″	79.20″	FEA	95%	92%	20.50″	1.02″	0.08″	0.22″	79.20″	3.96″	0.32″	0.83″
Wind Deformations with static wind - Dish	a7	peak	s2	x2/3	-	-	-	FEA	-	90%	0.02″	5.28″	0.53″	0.00″	-8.76″	-2.11″	-0.21″	0.00″
	a8	rms	r	-	x1	-	-	FEA	-	90%	3.57″	3.70″	0.37″	0.00″	6.26″	1.86″	0.19″	0.00″
Wind Deformations with static wind - Foundation	a9	peak	s2	x2/3	-	-	-	FEA (ICD)	-	90%	0.00″	0.05″	0.01″	0.00″	-1.02″	0.22″	0.02″	0.00″
	a10	rms	r	-	x1	-	-	FEA (ICD)	-	90%	0.04″	0.00″	0.00″	0.00″	0.62″	0.06″	0.01″	0.00″
Wind Deformation - Feeds	a11	peak	r	x2/3	x1/3	-	-	Spec	0%	90%	0.87″	0.87″	0.09″	0.09″	0.87″	0.87″	0.09″	0.09″
Environmental Influences (dynamic)																		
Wind gusts on Servo	b1	peak rms	s2	x1	-	-	-	E2E	-	-	0.03″	0.03″	0.03″	0.03″	0.23″	0.23″	0.23″	0.23″
	b2	rms	r	-	x1	-	-	E2E	-	-	0.12″	0.12″	0.12″	0.12″	0.15″	0.15″	0.15″	0.15″
Wind gusts on Structure	b3	peak rms	s2	x1	-	-	-	E2E	-	-	0.05″	0.05″	0.05″	0.09″	0.61″	0.61″	0.61″	1.03″
	b4	rms	r	-	x1	-	-	E2E	-	-	0.16″	0.16″	0.16″	0.27″	0.33″	0.33″	0.33″	0.55″
Mechanical																		
AZ Axis Missalignment NS/EW	c1	peak	r	x2/3	x1/3	15.00″	15.00″	Experience	95%	92%	3.88″	0.19″	0.02″	0.19″	15.00″	0.75″	0.06″	0.75″
Orthogonality AZ/EL-axis	c2	peak	r	x2/3	x1/3	15.00″	15.00″	Experience	95%	92%	3.88″	0.19″	0.02″	0.19″	3.88″	0.19″	0.02″	0.19″
AZ Bearing Run out Axial (wobble)	c3	peak	r	x2/3	x1/3	2.50″	2.50″	Experience	95%	92%	0.46″	0.02″	0.00″	0.02″	2.50″	0.13″	0.01″	0.13″
AZ/EL-Pos. Encoder Offset	c4	peak	r	x2/3	x1/3	9.00″	9.00″	Experience	99%	92%	8.69″	0.09″	0.01″	0.09″	9.00″	0.09″	0.01″	0.09″
EL-Bearing Run out Radial (wobble)	c5	peak	r	x2/3	x1/3	3.00″	0.00″	Experience	95%	92%	3.00″	0.15″	0.01″	0.15″	0.00″	0.00″	0.00″	0.00″
Sub Reflector Collimation accuracy	c6	peak	r	x2/3	x1/3	25.00″	25.00″	Experience	95%	92%	25.00″	1.25″	0.10″	0.10″	25.00″	1.25″	0.10″	0.10″
Feed Indexer Collimation accuracy	c7	peak	r	x2/3	x1/3	25.00″	25.00″	Experience	95%	92%	25.00″	1.25″	0.10″	0.10″	25.00″	1.25″	0.10″	0.10″
Feed Indexer Stability once indexed	c8	peak	r	x2/3	x1/3	1.90″	0.60″	Experience	0%	0%	1.90″	1.90″	1.90″	1.90″	0.60″	0.60″	0.60″	0.60″
Feed indexer positioning accuracy	c9	peak	r	x2/3	x1/3	0.61″	0.00″	Experience	0%	0%	0.61″	0.61″	0.61″	0.61″	0.00″	0.00″	0.00″	0.00″
Servo System																		
Control																		
Velocity lag	d1	peak	r	x2/3	x1/3	0.10″	0.10″	Experience	0%	0%	0.10″	0.10″	0.10″	0.10″	0.10″	0.10″	0.10″	0.10″
Acceleration lag	d2	peak	r	x2/3	x1/3	0.10″	0.10″	Experience	0%	0%	0.10″	0.10″	0.10″	0.10″	0.10″	0.10″	0.10″	0.10″
Program Track Interpolation	d3	peak	r	x2/3	x1/3	0.05″	0.05″	Experience	0%	0%	0.05″	0.05″	0.05″	0.05″	0.05″	0.05″	0.05″	0.05″
Time Synchronisation	d4	peak	r	x2/3	x1/3	0.05″	0.05″	Experience	0%	0%	0.05″	0.05″	0.05″	0.05″	0.05″	0.05″	0.05″	0.05″
Tiltmeter accuracy / noise	d5	peak	r	x2/3	x1/3	0.34″	0.34″	Datasheet	90%	92%	0.34″	0.34″	0.03″	0.20″	0.34″	0.34″	0.03″	0.20″
Drive																		
Backlash of drive units	d6	peak	r	x2/3	x1/3	0.02″	0.00″	Experience	0%	0%	0.01″	0.01″	0.01″	0.01″	0.00″	0.00″	0.00″	0.00″
Bearing and Gear Train Friction	d7	peak	r	x2/3	x1/3	0.25″	0.25″	Experience	0%	0%	0.24″	0.24″	0.24″	0.24″	0.25″	0.25″	0.25″	0.25″
Friction variation	d8	peak	r	x2/3	x1/3	0.25″	0.25″	Experience	0%	0%	0.24″	0.24″	0.24″	0.24″	0.25″	0.25″	0.25″	0.25″
Servo loop limit cycle (Friction)	d9	peak	r	x2/3	x1/3	0.50″	0.38″	Experience	0%	0%	0.48″	0.48″	0.48″	0.48″	0.38″	0.38″	0.38″	0.38″
Servo offset and noise	d10	peak	r	x2/3	x1/3	0.30″	0.23″	Experience	0%	0%	0.29″	0.29″	0.29″	0.29″	0.23″	0.23″	0.23″	0.23″
Motor cogging	d11	peak	r	x2/3	x1/3	0.25″	0.25″	Experience	0%	0%	0.24″	0.24″	0.24″	0.24″	0.25″	0.25″	0.25″	0.25″
Encoder																		
Encoder Precision RCN829	d12	peak	r	x2/3	x1/3	1.00″	1.00″	Datasheet	95%	0%	0.97″	0.05″	0.05″	0.05″	1.00″	0.05″	0.05″	0.05″
Encoder coupling	d13	peak	r	x2/3	x1/3	2.50″	1.50″	Experience	95%	92%	2.41″	0.12″	0.01″	0.01″	1.50″	0.08″	0.01″	0.01″
Encoder calibration (can be calibrated)	d14	peak	r	x2/3	x1/3	0.20″	0.20″	Datasheet	95%	92%	0.19″	0.01″	0.00″	0.00″	0.20″	0.01″	0.00″	0.00″
95% Error Circle																		
Margin [x-elev / elev]		20.0%									5.69″	0.87″	0.30″	0.30″	12.93″	1.11″	0.39″	0.56″
Total										2	28.43″	4.33″	1.52″	1.48″	64.67″	5.55″	1.95″	2.81″
Uncorrected total raw error / per Axis				rss							34.11″				77.61″			
MET+sPM-corrected: total blind pointing error / per Axis				rss								5.19″				6.66″		
MET+sPM+oPM-corrected: total reference pointing error / per Axis				rss									1.82″				2.34″	
Tracking Stability / per Axis				rss										1.78″				3.37″
total uncorrected Raw Pointing Error				vector length							84.77″							
MET+sPM-corrected: total Blind Pointing Error				vector length							8.45″							
MET+sPM+oPM-corrected: total Relative Pointing Error				vector length							2.96″							
total Tracking Stability				vector length							3.81″							
RMS																		
Margin [x-elev / elev]		20.0%									2.93″	0.77″	0.17″	0.17″	6.56″	0.61″	0.13″	0.19″
Total											14.67″	3.87″	0.85″	0.83″	32.81″	3.07″	0.63″	0.94″
Uncorrected total raw error / per Axis			rss								17.60				39.37			
MET+sPM-corrected: total blind pointing error / per Axis			rss									4.65″				3.69″		
MET+sPM+oPM-corrected: total reference pointing error / per Axis			rss										1.02″				0.75″	
Tracking Stability / per Axis			rss											0.99″				1.12″
total uncorrected Raw Pointing Error			vector length								43.13″							
MET+sPM-corrected: total Blind Pointing Error			vector length								5.93″							
MET+sPM+oPM-corrected: total Relative Pointing Error			vector length								1.27″							
total Tracking Stability			vector length								1.50″							

A tilt sensor is installed on the Pedestal just below the azimuth bearing. The advantage of the tilt sensor for correcting for steady state wind loads are illustrated in Table 72.

Table 72: Illustration of the Steady State Wind Error and Effect of a Tilt Sensor

No tilt sensor

Total error

Azimuth angle	Elevation angle							
	15	30	45	60	65	70	85	90
0°	9.8	9.8	8.9	7.7	7.4	7.3	6.9	6.5
45°	9.6	9.7	9.6	9.4	9.2	8.5	7.0	6.4
90°	5.1	5.1	4.8	4.4	4.3	4.2	4.0	3.9
135°	4.9	4.9	4.9	5.0	5.0	4.8	4.3	4.1
180°	6.0	6.1	6.5	7.1	7.2	6.9	6.2	5.7
225°	4.9	4.9	4.9	5.0	5.0	4.8	4.3	4.1
270°	5.1	5.1	4.8	4.4	4.3	4.2	4.0	3.9
315°	9.6	9.7	9.6	9.4	9.2	8.5	7.0	6.4
360	9.8	9.8	8.9	7.7	7.4	7.3	6.9	6.5

Elevation

Azimuth angle	Elevation angle							
	15	30	45	60	65	70	85	90
0°	9.8	9.8	8.9	7.7	7.4	7.3	6.9	6.5
45°	9.6	9.7	9.6	9.4	9.2	8.5	6.8	6.2
90°	0.3	0.3	0.3	0.2	0.2	0.3	0.6	0.8
135°	0.2	0.1	0.4	0.8	1.0	1.0	1.4	1.7
180°	6.0	6.1	6.5	7.1	7.2	6.9	6.2	5.7
225°	0.2	0.1	0.4	0.8	1.0	1.0	1.4	1.7
270°	0.3	0.3	0.3	0.2	0.2	0.3	0.6	0.8
315°	9.6	9.7	9.6	9.4	9.2	8.5	6.8	6.2
360°	9.8	9.8	8.9	7.7	7.4	7.3	6.9	6.5

Cross Elevation

Azimuth angle	Elevation angle							
	15	30	45	60	65	70	85	90
0°	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1
45°	0.8	0.7	0.7	0.6	0.4	0.1	1.7	1.8
90°	5.1	5.1	4.8	4.4	4.3	4.2	4.0	3.8
135°	4.9	4.9	4.9	4.9	4.9	4.6	4.0	3.8
180°	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1
225°	4.9	4.9	4.9	4.9	4.9	4.6	4.0	3.8
270°	5.1	5.1	4.8	4.4	4.3	4.2	4.0	3.8
315°	0.8	0.7	0.7	0.6	0.4	0.1	1.7	1.8
360°	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1

With tilt sensor

Total error

Elevation angle							
15	30	45	60	65	70	85	90
1.8	2.0	1.8	1.6	1.5	1.6	1.8	1.9
2.6	2.8	3.0	3.3	3.3	3.3	3.7	3.6
5.6	5.9	5.7	5.2	5.0	4.9	4.4	4.1
5.4	5.6	5.7	5.6	5.5	5.1	4.1	3.8
1.5	1.6	2.1	2.8	3.0	3.0	3.1	2.9
5.4	5.6	5.7	5.6	5.5	5.1	4.1	3.8
5.6	5.9	5.7	5.2	5.0	4.9	4.4	4.1
2.6	2.8	3.0	3.3	3.3	3.3	3.7	3.6
1.8	2.0	1.8	1.6	1.5	1.6	1.8	1.9

Elevation

Elevation angle							
15	30	45	60	65	70	85	90
1.8	2.0	1.8	1.6	1.5	1.6	1.8	1.9
2.5	2.7	2.9	3.2	3.3	3.3	3.2	3.1
1.9	1.9	1.7	1.5	1.4	1.5	1.5	1.6
1.7	1.7	1.4	1.0	0.9	0.8	0.4	0.2
1.5	1.6	2.1	2.8	3.0	3.0	3.1	2.9
1.7	1.7	1.4	1.0	0.9	0.8	0.4	0.2
1.9	1.9	1.7	1.5	1.4	1.5	1.5	1.6
2.5	2.7	2.9	3.2	3.3	3.3	3.2	3.1
1.8	2.0	1.8	1.6	1.5	1.6	1.8	1.9

Cross Elevation

Elevation angle							
15	30	45	60	65	70	85	90
0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1
0.8	0.8	0.7	0.6	0.4	0.2	1.8	1.8
5.3	5.5	5.4	5.0	4.8	4.7	4.1	3.8
5.1	5.3	5.5	5.5	5.4	5.1	4.1	3.8
0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1
5.1	5.3	5.5	5.5	5.4	5.1	4.1	3.8
5.3	5.5	5.4	5.0	4.8	4.7	4.1	3.8
0.8	0.8	0.7	0.6	0.4	0.2	1.8	1.8
0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1

6.3 Appendix: Product Breakdown Structure

DS Level	Identifier	Description	Type	Quantity
1	316-000000	Dish Structure	Develop	1
2	316-010000	Pedestal	Develop	1
3	316-010002	Pedestal Lower Section Welded Assembly	Develop	1
3	316-01xxxx	Pedestal Middle Section Welded Assembly	Develop	1
3	316-010004	Pedestal Upper Section	Develop	1
4	316-01xxxx	Upper Section Welded Assembly	Develop	2
4	316-01xxxx	Azimuth IO Unit Base	Develop	3
3	316-010006	Pedestal Door Installation	Develop	1
4	316-01xxxx	Pedestal Door	Develop	1
4	316-01xxxx	Pedestal Door Hinge	Develop	2
4	316-01xxxx	Inner Door Lock Assembly	Develop	1
4	316-01xxxx	Outer Door Lock Assembly	Develop	1
4	XYZ	Environmental Seal	COTS	ar
3	316-010008	PSC Door Installation	Develop	1
4	316-01xxxx	PSC Door	Develop	1
4	316-01xxxx	PSC Door Hinges	Develop	1
4	316-01xxxx	PSC Door Lock Mechanism	Develop	1
4	316-01xxxx	PSC Door Emergency Exit	Develop	1
4	XYZ	PSC Door EMI fingerstock	COTS	ar
3	316-010010	Pedestal Platform assembly	Develop	1
4	316-01xxxx	Fixed platform	Develop	1
5	316-01xxxx	Platform Bracket 1	Develop	1
5	316-01xxxx	Platform Bracket 2	Develop	1
5	316-01xxxx	Platform Bracket 3	Develop	1
5	316-01xxxx	Platform Bracket 4	Develop	1
5	316-01xxxx	Platform Step 1	Develop	1
5	316-01xxxx	Platform Step 2	Develop	1
5	316-01xxxx	Platform Step 3	Develop	1
4	316-01xxxx	Hatch assembly	Develop	1
5	316-01xxxx	Lock & anti-lock	Develop	1
5	316-01xxxx	Pin	Develop	1
5	316-01xxxx	Hinge bracket	Develop	2
5	316-01xxxx	Hinge	Develop	1
5	316-01xxxx	Hatch	Develop	1
5	316-01xxxx	Spring	Develop	6
3	316-01xxxx	Pedestal Lower Hatch	Develop	1
4	316-01xxxx	Hatch	Develop	1
4	316-01xxxx	Hatch Base	Develop	1
4	316-01xxxx	Hatch shaft	Develop	1
4	316-01xxxx	Spring	Develop	2
4	316-01xxxx	Handle	Develop	2
3	316-010012	Pedestal Ladder Lower Section Stow	Develop	1
3	316-01xxxx	Pedestal Ladder Lower Section	Develop	1
3	316-01xxxx	Pedestal Ladder Middle Section	Develop	1
3	316-01xxxx	Pedestal Ladder Middle Section 2	Develop	1
3	316-01xxxx	Pedestal Ladder Upper Section	Develop	1
2	316-020000	Turnhead	Develop	1
3	316-020002	Turnhead Welded Assembly	Develop	1
3	316-020004	Turnhead Hatch Installation	Develop	1
3	316-020006	Azimuth Actuator Assembly Cover	Develop	2
3	316-020008	Azimuth Bearing Cover	Develop	1
2	316-030000	Elevation Assembly	Develop	1
3	316-030002	Main Reflector Panels Set	Develop	1
4	316-030021	Panel 1-1	Develop	1
4	316-030022	Panel 1-2	Develop	1
4	316-030023	Panel 1-3	Develop	1
4	316-030024	Panel 1-4	Develop	1
4	316-030025	Panel 1-5	Develop	1
4	316-030026	Panel 1-6	Develop	1
4	316-030027	Panel 1-7	Develop	1
4	316-030028	Panel 1-8	Develop	1
4	316-030029	Panel 1-9	Develop	1
4	316-030030	Panel 1-10	Develop	1

DS Level	Identifier	Description	Type	Quantity
4	316-030031	Panel 1-11	Develop	1
4	316-030032	Panel 1-12	Develop	1
4	316-030033	Panel 1-13	Develop	1
4	316-030034	Panel 2-1	Develop	1
4	316-030035	Panel 2-2	Develop	1
4	316-030036	Panel 2-3	Develop	1
4	316-030037	Panel 2-4	Develop	1
4	316-030038	Panel 2-5	Develop	1
4	316-030039	Panel 2-6	Develop	1
4	316-030040	Panel 2-7	Develop	1
4	316-030041	Panel 2-8	Develop	1
4	316-030042	Panel 2-9	Develop	1
4	316-030043	Panel 2-10	Develop	1
4	316-030044	Panel 2-11	Develop	1
4	316-030045	Panel 2-12	Develop	1
4	316-030046	Panel 2-13	Develop	1
4	316-030047	Panel 3-1	Develop	1
4	316-030048	Panel 3-2	Develop	1
4	316-030049	Panel 3-3	Develop	1
4	316-030050	Panel 3-4	Develop	1
4	316-030051	Panel 3-5	Develop	1
4	316-030052	Panel 3-6	Develop	1
4	316-030053	Panel 3-7	Develop	1
4	316-030054	Panel 3-8	Develop	1
4	316-030055	Panel 3-9	Develop	1
4	316-030056	Panel 3-10	Develop	1
4	316-030057	Panel 3-11	Develop	1
4	316-030058	Panel 4-1	Develop	1
4	316-030059	Panel 4-2	Develop	1
4	316-030060	Panel 4-3	Develop	1
4	316-030061	Panel 4-4	Develop	1
4	316-030062	Panel 4-5	Develop	1
4	316-030063	Panel 4-6	Develop	1
4	316-030064	Panel 4-7	Develop	1
4	316-030065	Panel 4-8	Develop	1
4	316-030066	Panel 4-9	Develop	1
4	316-030067	Panel 4-10	Develop	1
4	316-030068	Panel 4-11	Develop	1
4	316-030069	Panel 5-1	Develop	1
4	316-030070	Panel 5-2	Develop	1
4	316-030071	Panel 5-3	Develop	1
4	316-030072	Panel 5-4	Develop	1
4	316-030073	Panel 5-5	Develop	1
4	316-030074	Panel 5-6	Develop	1
4	316-030075	Panel 5-7	Develop	1
4	316-030076	Panel 5-8	Develop	1
4	316-030077	Panel 5-9	Develop	1
4	316-030078	Panel 6-1	Develop	1
4	316-030079	Panel 6-2	Develop	1
4	316-030080	Panel 6-3	Develop	1
4	316-030081	Panel 6-4	Develop	1
4	316-030082	Panel 6-5	Develop	1
4	316-030083	Panel 6-6	Develop	1
4	316-030084	Panel 6-7	Develop	1
4	316-030085	Panel 6-8	Develop	1
4	316-030086	Panel 6-9	Develop	1
3	316-030004	Main Reflector BUS	Develop	1
4	316-03xxxx	Elevation-Turnhead Frame	Develop	1
4	316-03xxxx	Grantry Frame	Develop	1
4	316-03xxxx	V shape frame 1	Develop	1
4	316-03xxxx	V shape frame 2	Develop	1
4	316-03xxxx	V shape frame 3	Develop	1
4	316-03xxxx	V shape frame 4	Develop	1
4	316-03xxxx	Upper Chords Set	Develop	1
5	316-03xxxx	Upper Chord 1	Develop	1
5	316-03xxxx	Upper Chord 2	Develop	1
5	316-03xxxx	Upper Chord 3	Develop	1
5	316-03xxxx	Upper Chord 4	Develop	1
5	316-03xxxx	Upper Chord 5	Develop	1

DS Level	Identifier	Description	Type	Quantity
5	316-03xxxx	Upper Chord 6	Develop	1
5	316-03xxxx	Upper Chord 7	Develop	1
5	316-03xxxx	Upper Chord 8	Develop	2
5	316-03xxxx	Upper Chord 9	Develop	2
5	316-03xxxx	Upper Chord 10	Develop	2
5	316-03xxxx	Upper Chord 11	Develop	2
5	316-03xxxx	Upper Chord 12	Develop	2
5	316-03xxxx	Upper Chord 13	Develop	2
5	316-03xxxx	Upper Chord 14	Develop	2
5	316-03xxxx	Upper Chord 15	Develop	2
5	316-03xxxx	Upper Chord 16	Develop	2
5	316-03xxxx	Upper Chord 17	Develop	2
5	316-03xxxx	Upper Chord 18	Develop	2
5	316-03xxxx	Upper Chord 19	Develop	2
5	316-03xxxx	Upper Chord 20	Develop	2
5	316-03xxxx	Upper Chord 21	Develop	2
5	316-03xxxx	Upper Chord 22	Develop	2
5	316-03xxxx	Upper Chord 23	Develop	2
5	316-03xxxx	Upper Chord 24	Develop	2
5	316-03xxxx	Upper Chord 25	Develop	2
5	316-03xxxx	Upper Chord 26	Develop	2
5	316-03xxxx	Upper Chord 27	Develop	2
5	316-03xxxx	Upper Chord 28	Develop	2
5	316-03xxxx	Upper Chord 29	Develop	2
5	316-03xxxx	Upper Chord 30	Develop	2
5	316-03xxxx	Upper Chord 31	Develop	2
5	316-03xxxx	Upper Chord 32	Develop	2
5	316-03xxxx	Upper Chord 33	Develop	2
5	316-03xxxx	Upper Chord 34	Develop	2
5	316-03xxxx	Upper Chord 35	Develop	2
5	316-03xxxx	Upper Chord 36	Develop	2
5	316-03xxxx	Upper Chord 37	Develop	2
5	316-03xxxx	Upper Chord 38	Develop	2
5	316-03xxxx	Upper Chord 39	Develop	2
5	316-03xxxx	Upper Chord 40	Develop	2
5	316-03xxxx	Upper Chord 41	Develop	2
5	316-03xxxx	Upper Chord 42	Develop	2
5	316-03xxxx	Upper Chord 43	Develop	2
5	316-03xxxx	Upper Chord 44	Develop	2
5	316-03xxxx	Upper Chord 45	Develop	2
5	316-03xxxx	Upper Chord 46	Develop	2
5	316-03xxxx	Upper Chord 47	Develop	2
5	316-03xxxx	Upper Chord 48	Develop	2
5	316-03xxxx	Upper Chord 49	Develop	2
5	316-03xxxx	Upper Chord 50	Develop	2
5	316-03xxxx	Upper Chord 51	Develop	2
5	316-03xxxx	Upper Chord 52	Develop	2
5	316-03xxxx	Upper Chord 53	Develop	2
5	316-03xxxx	Upper Chord 54	Develop	2
5	316-03xxxx	Upper Chord 55	Develop	2
5	316-03xxxx	Upper Chord 56	Develop	2
5	316-03xxxx	Upper Chord 57	Develop	2
5	316-03xxxx	Upper Chord 58	Develop	2
4	316-03xxxx	Diagonals Set	Develop	1
5	316-03xxxx	Diagonal 1	Develop	2
5	316-03xxxx	Diagonal 2	Develop	2
5	316-03xxxx	Diagonal 3	Develop	2
5	316-03xxxx	Diagonal 4	Develop	2
5	316-03xxxx	Diagonal 5	Develop	2
5	316-03xxxx	Diagonal 6	Develop	2
5	316-03xxxx	Diagonal 7	Develop	2
5	316-03xxxx	Diagonal 8	Develop	2
5	316-03xxxx	Diagonal 9	Develop	2
5	316-03xxxx	Diagonal 10	Develop	2
5	316-03xxxx	Diagonal 11	Develop	2
5	316-03xxxx	Diagonal 12	Develop	2
5	316-03xxxx	Diagonal 13	Develop	2
5	316-03xxxx	Diagonal 14	Develop	2
5	316-03xxxx	Diagonal 15	Develop	2

DS Level	Identifier	Description	Type	Quantity
5	316-03xxxx	Diagonal 16	Develop	2
5	316-03xxxx	Diagonal 17	Develop	2
5	316-03xxxx	Diagonal 18	Develop	2
5	316-03xxxx	Diagonal 19	Develop	2
5	316-03xxxx	Diagonal 20	Develop	2
5	316-03xxxx	Diagonal 21	Develop	2
5	316-03xxxx	Diagonal 22	Develop	2
5	316-03xxxx	Diagonal 23	Develop	2
5	316-03xxxx	Diagonal 24	Develop	2
5	316-03xxxx	Diagonal 25	Develop	2
5	316-03xxxx	Diagonal 26	Develop	2
5	316-03xxxx	Diagonal 27	Develop	2
5	316-03xxxx	Diagonal 28	Develop	2
5	316-03xxxx	Diagonal 29	Develop	2
5	316-03xxxx	Diagonal 30	Develop	2
5	316-03xxxx	Diagonal 31	Develop	2
5	316-03xxxx	Diagonal 32	Develop	2
5	316-03xxxx	Diagonal 33	Develop	2
5	316-03xxxx	Diagonal 34	Develop	2
5	316-03xxxx	Diagonal 35	Develop	2
5	316-03xxxx	Diagonal 36	Develop	2
5	316-03xxxx	Diagonal 37	Develop	2
5	316-03xxxx	Diagonal 38	Develop	2
5	316-03xxxx	Diagonal 39	Develop	2
5	316-03xxxx	Diagonal 40	Develop	2
5	316-03xxxx	Diagonal 41	Develop	2
5	316-03xxxx	Diagonal 42	Develop	2
5	316-03xxxx	Diagonal 43	Develop	2
5	316-03xxxx	Diagonal 44	Develop	2
5	316-03xxxx	Diagonal 45	Develop	2
5	316-03xxxx	Diagonal 46	Develop	2
5	316-03xxxx	Diagonal 47	Develop	2
5	316-03xxxx	Diagonal 48	Develop	2
5	316-03xxxx	Diagonal 49	Develop	2
5	316-03xxxx	Diagonal 50	Develop	2
5	316-03xxxx	Diagonal 51	Develop	2
5	316-03xxxx	Diagonal 52	Develop	2
5	316-03xxxx	Diagonal 53	Develop	2
5	316-03xxxx	Diagonal 54	Develop	2
5	316-03xxxx	Diagonal 55	Develop	2
5	316-03xxxx	Diagonal 56	Develop	2
5	316-03xxxx	Diagonal 57	Develop	2
5	316-03xxxx	Diagonal 58	Develop	2
5	316-03xxxx	Diagonal 59	Develop	2
5	316-03xxxx	Diagonal 60	Develop	2
5	316-03xxxx	Diagonal 61	Develop	2
5	316-03xxxx	Diagonal 62	Develop	2
5	316-03xxxx	Diagonal 63	Develop	2
4	316-03xxxx	Lower Chords Set	Develop	1
5	316-03xxxx	Lower Chord 1	Develop	1
5	316-03xxxx	Lower Chord 2	Develop	1
5	316-03xxxx	Lower Chord 3	Develop	1
5	316-03xxxx	Lower Chord 4	Develop	2
5	316-03xxxx	Lower Chord 5	Develop	2
5	316-03xxxx	Lower Chord 6	Develop	2
5	316-03xxxx	Lower Chord 7	Develop	2
5	316-03xxxx	Lower Chord 8	Develop	2
5	316-03xxxx	Lower Chord 9	Develop	2
5	316-03xxxx	Lower Chord 10	Develop	2
5	316-03xxxx	Lower Chord 11	Develop	2
5	316-03xxxx	Lower Chord 12	Develop	2
5	316-03xxxx	Lower Chord 13	Develop	2
5	316-03xxxx	Lower Chord 14	Develop	2
5	316-03xxxx	Lower Chord 15	Develop	2
5	316-03xxxx	Lower Chord 16	Develop	2
5	316-03xxxx	Lower Chord 17	Develop	2
5	316-03xxxx	Lower Chord 18	Develop	2
5	316-03xxxx	Lower Chord 19	Develop	2
5	316-03xxxx	Lower Chord 20	Develop	2

DS Level	Identifier	Description	Type	Quantity
5	316-03xxxx	Lower Chord 21	Develop	2
5	316-03xxxx	Lower Chord 22	Develop	2
5	316-03xxxx	Lower Chord 23	Develop	2
5	316-03xxxx	Lower Chord 24	Develop	2
5	316-03xxxx	Lower Chord 25	Develop	2
5	316-03xxxx	Lower Chord 26	Develop	2
5	316-03xxxx	Lower Chord 27	Develop	2
5	316-03xxxx	Lower Chord 28	Develop	2
5	316-03xxxx	Lower Chord 29	Develop	2
5	316-03xxxx	Lower Chord 30	Develop	2
5	316-03xxxx	Lower Chord 31	Develop	2
5	316-03xxxx	Lower Chord 32	Develop	2
5	316-03xxxx	Lower Chord 33	Develop	2
5	316-03xxxx	Lower Chord 34	Develop	2
5	316-03xxxx	Lower Chord 35	Develop	2
5	316-03xxxx	Lower Chord 36	Develop	2
5	316-03xxxx	Lower Chord 37	Develop	2
5	316-03xxxx	Lower Chord 38	Develop	2
5	316-03xxxx	Lower Chord 39	Develop	2
4	316-03xxxx	Upper Knots Set	Develop	1
5	316-03xxxx	Upper Knot 1	Develop	1
5	316-03xxxx	Upper Knot 2	Develop	1
5	316-03xxxx	Upper Knot 3	Develop	1
5	316-03xxxx	Upper Knot 4	Develop	1
5	316-03xxxx	Upper Knot 5	Develop	1
5	316-03xxxx	Upper Knot 6	Develop	1
5	316-03xxxx	Upper Knot 7	Develop	1
5	316-03xxxx	Upper Knot 8	Develop	1
5	316-03xxxx	Upper Knot 9	Develop	1
5	316-03xxxx	Upper Knot 10	Develop	1
5	316-03xxxx	Upper Knot 11	Develop	1
5	316-03xxxx	Upper Knot 12	Develop	1
5	316-03xxxx	Upper Knot 13	Develop	1
5	316-03xxxx	Upper Knot 14	Develop	1
5	316-03xxxx	Upper Knot 15	Develop	1
5	316-03xxxx	Upper Knot 16	Develop	1
5	316-03xxxx	Upper Knot 17	Develop	1
5	316-03xxxx	Upper Knot 18	Develop	1
5	316-03xxxx	Upper Knot 19	Develop	1
5	316-03xxxx	Upper Knot 20	Develop	1
5	316-03xxxx	Upper Knot 21	Develop	1
5	316-03xxxx	Upper Knot 22	Develop	1
5	316-03xxxx	Upper Knot 23	Develop	1
5	316-03xxxx	Upper Knot 24	Develop	1
5	316-03xxxx	Upper Knot 25	Develop	1
5	316-03xxxx	Upper Knot 26	Develop	1
5	316-03xxxx	Upper Knot 27	Develop	1
5	316-03xxxx	Upper Knot 28	Develop	1
5	316-03xxxx	Upper Knot 29	Develop	1
5	316-03xxxx	Upper Knot 30	Develop	1
5	316-03xxxx	Upper Knot 31	Develop	1
5	316-03xxxx	Upper Knot 32	Develop	1
5	316-03xxxx	Upper Knot 33	Develop	1
5	316-03xxxx	Upper Knot 34	Develop	1
5	316-03xxxx	Upper Knot 35	Develop	1
5	316-03xxxx	Upper Knot 36	Develop	1
5	316-03xxxx	Upper Knot 37	Develop	1
5	316-03xxxx	Upper Knot 38	Develop	1
5	316-03xxxx	Upper Knot 39	Develop	1
5	316-03xxxx	Upper Knot 40	Develop	1
5	316-03xxxx	Upper Knot 41	Develop	1
5	316-03xxxx	Upper Knot 42	Develop	1
5	316-03xxxx	Upper Knot 43	Develop	1
5	316-03xxxx	Upper Knot 44	Develop	1
4	316-03xxxx	Lower Knots Set	Develop	1
5	316-03xxxx	Lower Knot 1	Develop	1
5	316-03xxxx	Lower Knot 2	Develop	1
5	316-03xxxx	Lower Knot 3	Develop	1
5	316-03xxxx	Lower Knot 4	Develop	1

DS Level	Identifier	Description	Type	Quantity
5	316-03xxxx	Lower Knot 5	Develop	1
5	316-03xxxx	Lower Knot 6	Develop	1
5	316-03xxxx	Lower Knot 7	Develop	1
5	316-03xxxx	Lower Knot 8	Develop	1
5	316-03xxxx	Lower Knot 9	Develop	1
5	316-03xxxx	Lower Knot 10	Develop	1
5	316-03xxxx	Lower Knot 11	Develop	1
5	316-03xxxx	Lower Knot 12	Develop	1
5	316-03xxxx	Lower Knot 13	Develop	1
5	316-03xxxx	Lower Knot 14	Develop	1
5	316-03xxxx	Lower Knot 15	Develop	1
5	316-03xxxx	Lower Knot 16	Develop	1
5	316-03xxxx	Lower Knot 17	Develop	1
5	316-03xxxx	Lower Knot 18	Develop	1
5	316-03xxxx	Lower Knot 19	Develop	1
5	316-03xxxx	Lower Knot 20	Develop	1
5	316-03xxxx	Lower Knot 21	Develop	1
5	316-03xxxx	Lower Knot 22	Develop	1
5	316-03xxxx	Lower Knot 23	Develop	1
5	316-03xxxx	Lower Knot 24	Develop	1
5	316-03xxxx	Lower Knot 25	Develop	1
5	316-03xxxx	Lower Knot 26	Develop	1
5	316-03xxxx	Lower Knot 27	Develop	1
5	316-03xxxx	Lower Knot 28	Develop	1
5	316-03xxxx	Lower Knot 29	Develop	1
5	316-03xxxx	Lower Knot 30	Develop	1
5	316-03xxxx	Lower Knot 31	Develop	1
5	316-03xxxx	Lower Knot 32	Develop	1
5	316-03xxxx	Lower Knot 33	Develop	1
5	316-03xxxx	Lower Knot 34	Develop	1
5	316-03xxxx	Lower Knot 35	Develop	1
5	316-03xxxx	Lower Knot 36	Develop	1
5	316-03xxxx	Lower Knot 37	Develop	1
5	316-03xxxx	Lower Knot 38	Develop	1
5	316-03xxxx	Lower Knot 39	Develop	1
5	316-03xxxx	Lower Knot 40	Develop	1
4	316-03xxxx	Central Chord	Develop	1
3	316-030006	Main Reflector Panel Adjuster	Develop	198
4	316-03xxxx	Adjuster Plate 1	Develop	1
4	316-03xxxx	Adjuster Plate 2	Develop	1
4	316-03xxxx	Adjuster Plate 3	Develop	1
4	316-03xxxx	Adjuster Plate 4	Develop	1
4	316-03xxxx	Adjuster Plate 5	Develop	1
4	316-03xxxx	Adjuster Plate 6	Develop	1
4	316-03xxxx	Adjuster Plate 7	Develop	1
4	316-03xxxx	Adjuster Plate 8	Develop	1
4	316-03xxxx	Adjuster Plate 9	Develop	1
4	316-03xxxx	Adjuster Plate 10	Develop	1
4	316-03xxxx	Adjuster Plate 11	Develop	1
4	316-03xxxx	Adjuster Plate 12	Develop	1
4	316-03xxxx	Adjuster Plate 13	Develop	1
4	316-03xxxx	Adjuster Plate 14	Develop	1
4	316-03xxxx	Adjuster Plate 15	Develop	1
4	316-03xxxx	Adjuster Plate 16	Develop	1
4	316-03xxxx	Adjuster Plate 17	Develop	1
4	316-03xxxx	Adjuster Plate 18	Develop	1
4	316-03xxxx	Adjuster Plate 19	Develop	1
4	316-03xxxx	Adjuster Plate 20	Develop	1
4	316-03xxxx	Adjuster Plate 21	Develop	1
4	316-03xxxx	Adjuster Plate 22	Develop	1
4	316-03xxxx	Adjuster Plate 23	Develop	1
4	316-03xxxx	Adjuster Plate 24	Develop	1
4	316-03xxxx	Adjuster Plate 25	Develop	1
4	316-03xxxx	Adjuster Plate 26	Develop	1
4	316-03xxxx	Adjuster Plate 27	Develop	1
4	316-03xxxx	Adjuster Plate 28	Develop	1
4	316-03xxxx	Adjuster Plate 29	Develop	1
4	316-03xxxx	Adjuster Plate 30	Develop	1
4	316-03xxxx	Adjuster Plate 31	Develop	1

DS Level	Identifier	Description	Type	Quantity
4	316-03xxxx	Adjuster Plate 32	Develop	1
4	316-03xxxx	Adjuster Plate 33	Develop	1
4	316-03xxxx	Adjuster Plate 34	Develop	1
4	316-03xxxx	Adjuster Plate 35	Develop	1
4	316-03xxxx	Adjuster Plate 36	Develop	1
4	316-03xxxx	Adjuster Plate 37	Develop	1
4	316-03xxxx	Adjuster Plate 38	Develop	1
4	316-03xxxx	Adjuster Plate 39	Develop	1
4	316-03xxxx	Adjuster Plate 40	Develop	1
4	316-03xxxx	Adjuster Plate 41	Develop	1
4	316-03xxxx	Adjuster Plate 42	Develop	1
4	316-03xxxx	Adjuster Plate 43	Develop	1
4	316-03xxxx	Adjuster Plate 44	Develop	1
4	316-03xxxx	Adjuster Plate 45	Develop	1
4	316-03xxxx	Adjuster Plate 46	Develop	1
4	316-03xxxx	Adjuster Plate 47	Develop	1
3	316-030008	Support Arm	Develop	1
4	316-030008	Support Arm Chord Set	Develop	1
5	316-03xxxx	Arm Chord 1	Develop	1
5	316-03xxxx	Arm Chord 2	Develop	1
5	316-03xxxx	Arm Chord 3	Develop	2
5	316-03xxxx	Arm Chord 4	Develop	2
5	316-03xxxx	Arm Chord 5	Develop	2
5	316-03xxxx	Arm Chord 6	Develop	2
5	316-03xxxx	Arm Chord 7	Develop	2
5	316-03xxxx	Arm Chord 8	Develop	2
5	316-03xxxx	Arm Chord 9	Develop	2
5	316-03xxxx	Arm Chord 10	Develop	2
5	316-03xxxx	Arm Chord 11	Develop	2
5	316-03xxxx	Arm Chord 12	Develop	2
5	316-03xxxx	Arm Chord 13	Develop	2
5	316-03xxxx	Arm Chord 14	Develop	2
5	316-03xxxx	Arm Chord 15	Develop	2
5	316-03xxxx	Arm Chord 16	Develop	2
5	316-03xxxx	Arm Chord 17	Develop	2
5	316-03xxxx	Arm Chord 18	Develop	2
5	316-03xxxx	Arm Chord 19	Develop	2
4	316-03xxxx	Support Arm Knots Set	Develop	1
5	316-03xxxx	Arm Knot 1A	Develop	1
5	316-03xxxx	Arm Knot 2A	Develop	1
5	316-03xxxx	Arm Knot 3A	Develop	1
5	316-03xxxx	Arm Knot 4A	Develop	1
5	316-03xxxx	Arm Knot 5A	Develop	1
5	316-03xxxx	Arm Knot 6A	Develop	1
5	316-03xxxx	Arm Knot 7A	Develop	1
5	316-03xxxx	Arm Knot 8A	Develop	1
5	316-03xxxx	Arm Knot 9A	Develop	1
3	316-030010	Sub Reflector	Develop	1
4	316-03xxxx	Sub Reflector Panel Central	Develop	1
4	316-03xxxx	Sub Reflector Panel Outer 1	Develop	1
4	316-03xxxx	Sub Reflector Panel Outer 2	Develop	1
4	316-03xxxx	Sub Reflector Panel Outer 3	Develop	1
4	316-03xxxx	Sub Reflector Panel Outer 4	Develop	1
4	316-03xxxx	Sub Reflector Panel Outer 5	Develop	1
3	316-030012	Sub Reflector BUS	Develop	1
4	316-03xxxx	Diagonel Chord 1 Assembly	Develop	6
4	316-03xxxx	Diagonel Chord 2 Assembly	Develop	5
4	316-03xxxx	Diagonel Chord 3 Assembly	Develop	5
4	316-03xxxx	Diagonel Chord 4 Assembly	Develop	10
4	316-03xxxx	Diagonel Chord 5 Assembly	Develop	4
4	316-03xxxx	Sub Reflector Knot 1	Develop	1
4	316-03xxxx	Sub Reflector Knot 2	Develop	1
4	316-03xxxx	Sub Reflector Knot 3	Develop	1
4	316-03xxxx	Sub Reflector Knot 4	Develop	1
4	316-03xxxx	Sub Reflector Knot 5	Develop	1
4	316-03xxxx	Sub Reflector Knot 6	Develop	1
4	316-03xxxx	Sub Reflector Knot 7	Develop	1
4	316-03xxxx	Sub Reflector Knot 8	Develop	1
4	316-03xxxx	Sub Reflector Knot 9	Develop	1

DS Level	Identifier	Description	Type	Quantity
4	316-03xxxx	Sub Reflector Knot 10	Develop	1
4	316-03xxxx	Sub Reflector Knot 11	Develop	1
4	316-03xxxx	Sub Reflector Knot 12	Develop	1
4	316-03xxxx	Sub Reflector Knot 13	Develop	1
4	316-03xxxx	Sub Reflector Knot 14	Develop	1
4	316-03xxxx	Sub Reflector Knot 15	Develop	1
4	316-03xxxx	Adjuster Rod Central	Develop	15
4	316-03xxxx	Adjuster Rod Central 1	Develop	3
4	316-03xxxx	Adjuster Rod Outer	Develop	15
4	316-03xxxx	Adjuster Rod Outer 1	Develop	3
4	316-03xxxx	Adjuster Rod Outer 2	Develop	5
4	316-03xxxx	Adjuster Rod Outer 3	Develop	2
4	316-03xxxx	Interface Base 1	Develop	2
4	316-03xxxx	Interface Base 2	Develop	1
4	316-03xxxx	Interface Base 3	Develop	10
4	316-03xxxx	Developed Items	Develop	n
3	316-030014	Feed Indexer Support	Develop	1
4	316-03xxxx	Fixed Platform	Develop	1
5	316-03xxxx	Arm Chord 20 Asm	Develop	1
5	316-03xxxx	Arm Chord 21 Asm	Develop	2
5	316-03xxxx	Arm Knot 10A	Develop	1
5	316-03xxxx	Arm Knot 11A	Develop	1
5	316-03xxxx	Arm Knot 12A	Develop	1
4	316-03xxxx	Moving Platform	Develop	1
5	316-03xxxx	Base 1	Develop	1
5	316-03xxxx	Base 2	Develop	1
5	316-03xxxx	Base 3	Develop	1
5	316-03xxxx	Indexer Interface plate	Develop	1
4	316-03xxxx	Fulcrum Bar	COTS	2
4	316-03xxxx	Fulcrum Bar	COTS	4
3	316-030016	Counterweight Assembly	Develop	1
4	316-03xxxx	Adjustable Plate	Develop	1
4	316-03xxxx	Counterweight Chord 1	Develop	1
4	316-03xxxx	Counterweight Chord 2	Develop	2
4	316-03xxxx	Counterweight Chord 3	Develop	2
4	316-03xxxx	Counterweight Chord 4	Develop	2
4	316-03xxxx	Counterweight Chord 5	Develop	2
4	316-03xxxx	Counterweight Chord 6	Develop	2
4	316-03xxxx	Counterweight Knot 1	Develop	1
4	316-03xxxx	Counterweight Knot 2	Develop	1
4	316-03xxxx	Counterweight Knot 3	Develop	1
4	316-03xxxx	Counterweight Knot 4	Develop	1
4	316-03xxxx	Counterweight Knot 5	Develop	1
4	316-03xxxx	Counterweight Knot 6	Develop	1
4	316-03xxxx	Counterweight Box	Develop	2
4	316-03xxxx	Counterweight Bar	Develop	2
3	316-03xxxx	Sub Reflector Extension	Develop	1
4	316-03xxxx	Sub Reflector Extension Panel Left	Develop	1
4	316-03xxxx	Sub Reflector Extension Panel Right	Develop	1
4	316-03xxxx	Sub Reflector Extension Panel Central	Develop	1
3	316-03xxxx	Branch 1	Develop	2
3	316-03xxxx	Branch 2	Develop	2
3	316-03xxxx	Branch 3	Develop	2
3	316-03xxxx	Branch 4	Develop	1
3	316-03xxxx	Adjustable Rod 1	Develop	2
3	316-03xxxx	Adjustable Rod 2	Develop	2
3	316-03xxxx	Adjustable Rod 3	Develop	2
3	316-03xxxx	Adjustable Rod 4	Develop	2
2	316-040000	Feed Indexer	Develop	1
3	316-040100	Mounting Interface & Motors Support Assembly	Develop	1
4	316-040101	Motors Support Plate	Develop	1
4	316-040102	Motors Support Flange	Develop	2
3	316-040200	Center Tube Assembly	Develop	1
4	316-040201	Center Tube	Develop	1
4	316-040202	Inner Bearing Bush	Develop	1
3	316-040300	Bearing System Assembly	Develop	1
4	316-040301	Tapered Roller Bearing	COTS	2
4	316-040302	Filler	Develop	1
4	316-040303	Preload Flange Locking Assembly	Develop	1

DS Level	Identifier	Description	Type	Quantity
5	316-040304	Preload Flange	Develop	1
5	316-040305	Pin Guide Assembly	Develop	1
4	316-040306	Preload Elastic Belleville Spring Pack Assembly	Develop	1
5	316-040307	Preload Elastic Belleville Spring Pack	Develop	20
4	316-040309	Inner lower bearing shield	Develop	1
4	316-040310	Locking Flange	Develop	1
4	316-040311	Lubrication System	COTS	1
4	316-040312	Gasket OR D5 R 242 Assembly	COTS	1
5	316-040318	Grease Fitting	COTS	6
5	316-040319	Grease Drain Trap	COTS	3
3	316-040400	Main Platform Assembly	Develop	1
4	316-040401	Main Platform	Develop	1
5	316-040403	Upper Structure	Develop	1
5	316-040408	Lower Structure	Develop	1
4	316-040402	Gear Wheel	Develop	1
3	316-040500	Maintenance Walkable Platform Support Structure Assembly	Develop	1
4	316-040501	Central Support Structure	Develop	1
4	316-040502	Central Support Bracket Type A	Develop	8
4	316-040503	Cable Support Bracket	Develop	1
4	316-040507	Nutsert 09468-00413 Gathered	COTS	24
3	316-040700	Harness Support & Protections	Develop	1
4	316-040701	Cables Protection Grids Assembly	Develop	3
5	316-040702	Omega bracket fixing grid	Develop	2
5	316-040703	WMCT Cable Protection	Develop	1
4	316-040704	Lateral Cables Support	Develop	1
4	316-040709	Cable Support Grid Assy	Develop	1
3	316-040800	Equipment Mounts Assembly	Develop	1
4	316-040801	Equipment Guide Supports	Develop	3
5	316-040805	Equipment Support Guide	Develop	1
4	316-040802	Equipment Plate Support	Develop	1
5	316-040806	M1140-0001 Support Assembly	Develop	1
5	316-040807	Vacuum Pump Support Assembly	Develop	1
5	316-040808	Power Distribution Support Assembly	Develop	1
4	316-040804	SPF Band Support Assembly	Develop	3
3	316-041100	Limit Switches & Hard Stops	Develop	1
4	316-041101	Limit Switches Assembly	Develop	1
5	316-041105	Limit Switches	COTS	2
5	316-041106	Limit Mechanical blocks	Develop	1
5	316-041107	Fastners Assembly	COTS	1
4	316-041102	Endstop Top Assembly	Develop	1
5	316-041108	Endstop Locking Bracket Assembly	Develop	1
5	316-041103	Endstop Buffers	Develop	2
3	316-041200	Dust & RF Protections	Develop	1
4	316-041201	Lower Dust Protection Shield Assembly	Develop	1
4	316-041202	Top Gasket	COTS	1
4	316-041203	Upper Cover Assembly	Develop	1
4	316-041204	Edge Protection	Develop	1
4	316-041205	Central Support Closure Assembly	Develop	1
3	316-041300	Cable Wrap	Develop	1
4	316-041301	Cable Wrap Bracket	Develop	2
4	316-041302	System Triflex R Series TRE-100	COTS	1
2	316-050000	DS Plant Installations	Develop	1
3	316-050500	Power Distribution System	Develop	1
4	316-050501	Pedestal Power Distribution Panel Installation	Develop	1
5	316-05xxxx	Pedestal Power Distribution Panel	Develop	1
6	316-05xxxx	Enclosure A	Develop	1
6	XYZ	Disconnector 4P 100A	COTS	1
6	XYZ	Circuit breaker-Light 200W C16A/2P	COTS	1
6	XYZ	Circuit breaker-Auxiliary Switch 500W C16A/2P	COTS	1
6	XYZ	Circuit breaker-PSC 12kW D63A/4P	COTS	1
6	XYZ	Circuit breaker-Compressor 6kW D32A/4P	COTS	1
6	XYZ	Circuit breaker-Backup 6kW D32A/4P	COTS	1
6	XYZ	Circuit breaker-Indexer 3kW D20A/4P	COTS	1
6	XYZ	Circuit breaker-Socket 500W C20A/2P	COTS	1
6	XYZ	Circuit breaker-Lightning Protection 12kW C63A/4P	COTS	1
6	XYZ	Remote control Auxiliary RCA 4P	COTS	3
6	XYZ	iOF	COTS	4
6	XYZ	Socket Leakage protection VEA 30mA	COTS	1
6	XYZ	Surge Arrester PRF12.5r 3P+N	COTS	1

DS Level	Identifier	Description	Type	Quantity
6	XYZ	Relay RXM4CB2BD	COTS	3
6	XYZ	Wire…(inside the Box)	COTS	ar
6	XYZ	Cable gland M40	COTS	1
6	XYZ	Cable gland M32	COTS	1
6	XYZ	Cable gland M25	COTS	1
6	XYZ	Cable gland M20	COTS	3
6	XYZ	Cable gland M16	COTS	3
5	XYZ	Wire to Helium Compressor	COTS	1
5	XYZ	Wire to Indexer PDU	COTS	1
5	XYZ	Wire to PSC Earth EMI Filter	COTS	1
5	XYZ	Wire to PSC Power EMI Filter	COTS	1
5	XYZ	Wire to Utility Socket	COTS	1
5	XYZ	Wire to pedestal light-1st floor	COTS	1
5	XYZ	Wire to pedestal light-2nd floor	COTS	1
5	XYZ	Wire to pedestal light-3rd floor 2x1.0	COTS	1
5	XYZ	Wire to pedestal light-turnhead 2x1.0	COTS	1
4	316-050502	PSC Power Distribution Panel Installation	Develop	1
5	316-05xxxx	PSC Power Distribution Panel	Develop	1
6	316-05xxxx	Enclosure B	Develop	1
6	XYZ	Disconnector 4P 80A	COTS	1
6	XYZ	Circuit breaker-Light 200W C16A/2P	COTS	1
6	XYZ	Circuit breaker-UPS 9kW D40A/4P	COTS	1
6	XYZ	Circuit breaker-Voltage Detection B3A/4P	COTS	1
6	XYZ	Circuit breaker-Backup EMISC 3kW D20A/2P	COTS	1
6	XYZ	Circuit breaker-Ventilation 600W D6A/2P	COTS	1
6	XYZ	Circuit breaker-Auxiliary Switch 3kW D16A/4P	COTS	1
6	XYZ	Circuit breaker-Socket 200W C20A/2P	COTS	1
6	XYZ	Circuit breaker-lightning protection C40A/4P	COTS	1
6	XYZ	Surge Arrester PRU40 3P+N	COTS	1
6	XYZ	Remote control Auxiliary RCA 4P	COTS	1
6	XYZ	Remote control Auxiliary RCA 2P	COTS	2
6	XYZ	iOF	COTS	4
6	XYZ	Socket Leakage protection VEA 30mA	COTS	1
6	XYZ	Relay RXM4CB2BD	COTS	3
6	XYZ	Current Transformer 4NC5117	COTS	3
6	XYZ	Wire inside box	COTS	ar
6	XYZ	Cable gland M32	COTS	1
6	XYZ	Cable gland M25	COTS	1
6	XYZ	Cable gland M20	COTS	4
6	XYZ	Cable gland M16	COTS	3
5	XYZ	Wheels	COTS	4
5	XYZ	Wire to Utility Socket 3X1.5	COTS	1
5	XYZ	Wire to PSC light 2x1.0	COTS	1
5	XYZ	Wire to PSC inlet Fan	COTS	1
5	XYZ	Wire to PSC outlet Fan	COTS	1
5	XYZ	Wire to PSC Earth EMI Filter	COTS	1
5	XYZ	Wire to PSC Power EMI Filter	COTS	1
5	XYZ	Wire to Monitor	COTS	1
4	316-050503	Feed Indexer Power Distribution Panel Installation	Develop	1
5	316-05xxxx	Feed Indexer Power Distribution Panel	Develop	1
6	316-05xxxx	Enclosure C	Develop	1
6	XYZ	Disconnector 4P 32A	COTS	1
6	XYZ	Circuit breaker-Vacuum 2kW D10A/4P	COTS	1
6	XYZ	Circuit breaker-Backup 2kW D10A/4P	COTS	1
6	XYZ	Circuit breaker-Backup 500W C10A/2P	COTS	1
6	XYZ	Circuit breaker-SPF B1 200W C6A/2P	COTS	1
6	XYZ	Circuit breaker-SPF B2 200W C6A/2P	COTS	1
6	XYZ	Circuit breaker-SPF B345 200W C6A/2P	COTS	1
6	XYZ	Circuit breaker-RXS B123 100W C6A/2P	COTS	1
6	XYZ	Circuit breaker-RXS B45 100W C6A/2P	COTS	1
6	XYZ	Circuit breaker C16A/2P VEA 30mA	COTS	1
6	XYZ	Socket 16A	COTS	1
6	XYZ	iOF	COTS	8
6	XYZ	Socket Leakage protection VEA 30mA	COTS	1
6	XYZ	Wire inside box	COTS	ar
6	XYZ	Wire…	COTS	ar
6	XYZ	Cable Connector	COTS	TBD
6	XYZ	Cable Connector	COTS	TBD
5	316-05xxxx	Wire to SPF Vaccum	Develop	1

DS Level	Identifier	Description	Type	Quantity
5	316-05xxxx	Wire to SPF Band1	Develop	1
5	316-05xxxx	Wire to SPF Band2	Develop	1
5	316-05xxxx	Wire to SPF Band345	Develop	1
5	316-05xxxx	Wire to Rx Band123	Develop	1
5	316-05xxxx	Wire to Rx Band45	Develop	1
5	316-05xxxx	Wire to Monitor	Develop	1
5	316-05xxxx	Wire to SPF SPARE1	Develop	1
5	316-05xxxx	Wire to SPF SPARE2	Develop	1
4	316-050504	Utility Socket Installation	Develop	1
5	XYZ	Utility Socket Unit	COTS	2
5	XYZ	Wire	COTS	ar
4	316-050505	Lights Installation	Develop	1
5	XYZ	Light Fitting	COTS	5
5	XYZ	Light Bulp	COTS	5
5	XYZ	Light Switch	COTS	2
5	XYZ	Wire…	COTS	ar
4	XYZ	PSC Power EMI Filter set	COTS	1
5	XYZ	PSC Power EMI Filter	COTS	1
5	XYZ	PSC Earth EMI Filter	COTS	1
4	316-050508	UPS Installation	Develop	n
5	XYZ	UPS	COTS	1
5	XYZ	Batteries	COTS	TBD
5	316-05xxxx	Mounting Bracket	Develop	n
3	316-051000	EMI Shielded Cabinet	Develop	1
4	316-051xxx	19" Cabinet	Develop	1
4	XYZ	19" Cabinet Outlet Fan	COTS	3
4	316-051xxx	19" rack L-bracket (left)	Develop	10
4	316-051xxx	19" rack L-bracket (right)	Develop	10
4	XYZ	19" rack Fan Unit	COTS	2
4	XYZ	19" rack 1U Blanking Plate	COTS	10
4	XYZ	19" rack Sliding Tray	COTS	1
4	XYZ	19" rack Power Distribution Unit	COTS	1
4	316-051xxx	19" Cabinet Power Filter	Develop	1
3	316-051500	Azimuth Bearing Installation	Develop	1
4	XYZ	Azimuth Bearing	COTS	1
4	XYZ	Automatic Grease System	COTS	2
3	316-052000	Elevation Bearing Installation	Develop	1
4	XYZ	Elevation Bearing	COTS	2
4	316-05xxxx	Elevation Assembly Bracket	Develop	1
5	316-05xxxx	Left Bracket	Develop	1
5	316-05xxxx	Right Bracket	Develop	1
5	316-05xxxx	Bridging Plate	Develop	1
4	316-05xxxx	Left Bearing Asm	Develop	1
4	316-05xxxx	Right Bearing Asm	Develop	1
4	XYZ	Grease Seal	COTS	1
4	XYZ	Grease Seal	COTS	3
4	XYZ	Grease Nipple	COTS	6
3	316-053000	Lightning Protection Installation	Develop	1
4	316-05xxxx	Lightning Protection Rod 1 (Main reflector)	Develop	2
4	316-05xxxx	Lightning Protection Rod 2(Main Reflector)	Develop	1
4	316-05xxxx	Lightning Protection Rod 3(Main Reflector)	Develop	2
4	316-05xxxx	Lightning Protection Rod 1(Sub Reflector)	Develop	2
4	316-05xxxx	Lightning Downconductor System	Develop	1
5	316-05xxxx	Plate 1	Develop	4
5	316-05xxxx	Plate 2	Develop	1
5	316-05xxxx	Plate 3	Develop	2
5	316-05xxxx	Plate 4	Develop	1
5	XYZ	Connector1	COTS	14
5	XYZ	Connector2	COTS	20
5	XYZ	Connector3	COTS	10
5	XYZ	Connector4	COTS	10
5	XYZ	Cable1	COTS	ar
5	XYZ	Cable2	COTS	ar
4	316-05xxxx	Azimuth Slipring	Develop	4
5	XYZ	Copper Braid Belt	COTS	1
5	316-05xxxx	Mechanical Parts	Develop	n
4	316-05xxxx	Elevation Lightning	Develop	2
5	XYZ	Copper Braid Belt	COTS	1
5	316-05xxxx	Mechanical Parts	Develop	n

DS Level	Identifier	Description	Type	Quantity
3	316-053500	Azimuth Cable Wrap Installation	Develop	1
4	316-05xxxx	Sliding Sleeve	Develop	n
4	316-05xxxx	Cable Wrap Shaft	Develop	1
4	316-05xxxx	Inner Ring	Develop	10
4	316-05xxxx	Outer Ring	Develop	10
4	XYZ	Wire	COTS	4
3	316-054000	Elevation Cable Wrap Installation	Develop	1
4	316-05xxxx	Cable Wrap Bracket 1	Develop	1
4	316-05xxxx	Cable Wrap Bracket2	Develop	1
4	XYZ	Cable Wrap	COTS	n
3	316-054500	Cable Ducting Installation	Develop	1
4	316-05xxxx	Cable Ducting Pedestal	Develop	1
5	XYZ	Cable Tray 54/300 903	COTS	1
5	XYZ	Cable Tray 54/300 1500	COTS	1
5	XYZ	Cable Tray 54/300 2500	COTS	2
5	XYZ	Cable Tray 54/300 2800	COTS	1
5	XYZ	Cable Tray 54/300 4800	COTS	2
5	316-05xxxx	Accessories	Develop	n
5	316-05xxxx	Accessories	Develop	n
5	316-05xxxx	Accessories	Develop	n
5	316-05xxxx	Accessories	Develop	n
5	316-05xxxx	Accessories	Develop	n
4	316-05xxxx	Cable Out Routing Box Turnhead	Develop	1
4	316-05xxxx	Cable Ducting Assembly-Elevation Assembly	Develop	1
5	316-05xxxx	Cable Ducting Sub-Assembly 1	Develop	1
5	316-05xxxx	Cable Ducting Sub-Assembly 2	Develop	1
5	316-05xxxx	Cable Ducting Sub-Assembly 3	Develop	1
5	316-05xxxx	Cable Ducting Sub-Assembly 4	Develop	1
5	316-05xxxx	Cable Ducting Sub-Assembly 5	Develop	1
5	316-05xxxx	Cable Ducting Sub-Assembly 6	Develop	1
5	316-05xxxx	Cable Ducting Sub-Assembly 7	Develop	1
5	316-05xxxx	Cable Ducting Sub-Assembly Tran 1	Develop	1
5	316-05xxxx	Cable Ducting Sub-Assembly Tran 2	Develop	1
3	316-055000	Helium System Mount Installation	Develop	1
4	316-05xxxx	Helium Compressor Bracket	Develop	1
4	316-05xxxx	Helium Replenish Bottle Cover	Develop	1
4	316-05xxxx	Helium Bottle Fixed Pulley	Develop	1
5	316-05xxxx	Pulley Wheel	Develop	1
5	316-05xxxx	Pulley Wheel Shaft	Develop	1
4	316-05xxxx	Helium Bottle Pin	Develop	1
4	XYZ	Bottle Hose Clamp	COTS	2
4	XYZ	Ground wire	COTS	1
4	XYZ	Earthing Terminal	COTS	1
4	316-05xxxx	Helium System Mounting	Develop	1
3	316-055500	HVAC Installation	Develop	1
4	XYZ	Pedestal Door Air filter	COTS	1
4	XYZ	PSC Fans	COTS	4
4	XYZ	PSC Ventilation Ari Filter	COTS	4
4	316-05xxxx	Ventilation Cover Left	Develop	1
4	316-05xxxx	Ventilation Cover Right	Develop	1
4	316-05xxxx	SunShield	Develop	1
3	316-05xxxx	EMISC Bracket	Develop	1
2	316-060000	DS Control System	Develop	1
3	316-060500	Drive Cabinet	Develop	1
4	316-060xxx	Software & Configuration files	Develop	1
5	316-060xxx	Software Realtime OS	Develop	1
5	316-060xxx	Software Windows OS (Maintenance)	Develop	1
5	316-060xxx	DS Controller Software	Develop	1
5	316-060xxx	DC Controller Configuration	Develop	1
5	316-060xxx	Azimuth Motor Amplifier Configuration	Develop	1
5	316-060xxx	Elevation Motor Amplifier Configuration	Develop	1
5	316-060xxx	Feed Indexer Motor Amplifier Configuration	Develop	1
4	316-060xxx	Cabinet	Develop	1
4	XYZ	DS Controller	COTS	1
4	XYZ	SingleDrive, 11kW, 23.5A	COTS	1
4	XYZ	DC rail kit up to 23,5A	COTS	1
4	XYZ	SingleDrive, 11kW, 23.5A	COTS	1
4	XYZ	DC rail kit up to 23,5A	COTS	1
4	XYZ	SingleDrive, 11kW, 23.5A	COTS	1

DS Level	Identifier	Description	Type	Quantity
4	XYZ	MultiDrive, 1.5kW, 4A	COTS	1
4	XYZ	MultiDrive, 1.5kW, 4A	COTS	1
4	XYZ	Line Filter 31A, 0,75mH	COTS	1
4	XYZ	Line Filter 31A, 0,75mH	COTS	1
4	XYZ	Line Filter 31A, 0,75mH	COTS	1
4	XYZ	Brake Resistor 18Ω, 1200W	COTS	1
4	XYZ	Brake Resistor 18Ω, 1200W	COTS	1
4	316-060xxx	Servo IO Unit	Develop	1
5	XYZ	EtherCAT E-Bus	COTS	1
5	XYZ	Endcap	COTS	1
5	XYZ	EtherCAT Terminal - field supply	COTS	1
5	XYZ	EtherCAT Terminal - 4-channel analog input	COTS	1
5	XYZ	EtherCAT Terminal - 16-channel digital input	COTS	1
5	XYZ	EtherCAT Terminal - TwinSAFE Logic	COTS	1
5	XYZ	EtherCAT Terminal - 4-channel digital input, TwinSAFE	COTS	1
5	XYZ	EtherCAT Terminal - 4-channel digital input, TwinSAFE	COTS	1
5	XYZ	EtherCAT Terminal - 4-channel digital input, TwinSAFE	COTS	1
5	XYZ	EtherCAT Terminal - 4-channel digital output, TwinSAFE	COTS	1
5	XYZ	EtherCAT Terminal - 4-channel digital input, TwinSAFE	COTS	1
5	XYZ	EtherCAT Terminal - 16-channel digital input	COTS	1
5	XYZ	EtherCAT Terminal - 16-channel digital output	COTS	1
5	XYZ	EtherCAT Terminal - 16-channel digital output	COTS	1
5	XYZ	EtherCAT Terminal - EtherCAT fibre optic junction	COTS	1
4	316-060xxx	Auxillary IO Unit	Develop	1
5	XYZ	EtherCAT E-Bus	COTS	1
5	XYZ	Endcap	COTS	1
5	XYZ	EtherCAT Terminal - field supply	COTS	1
5	XYZ	EtherCAT Terminal - 16-channel digital input	COTS	1
5	XYZ	EtherCAT Terminal - 8-channel digital output	COTS	1
5	XYZ	EtherCAT Terminal - 2-channel input PT100	COTS	1
5	XYZ	EtherCAT Terminal - 2-channel input PT100	COTS	1
5	XYZ	EtherCAT Terminal - 2-channel analog input	COTS	1
5	XYZ	EtherCAT Terminal - 2-channel analog input	COTS	1
5	XYZ	EtherCAT Terminal - 2-channel analog input	COTS	1
5	XYZ	EtherCAT Terminal - 2-channel analog input	COTS	1
5	XYZ	EtherCAT Terminal - 3-phase power mearuement	COTS	1
4	XYZ	Miniature Circuit Breaker, 4A	COTS	2
4	XYZ	Miniature Circuit Breaker, 8A	COTS	2
4	XYZ	Fiber Optic Ethernet Converter	COTS	2
4	XYZ	Expansion module	COTS	4
4	XYZ	Miniature Circuit Breaker, 10A	COTS	1
4	XYZ	Miniature Circuit Breaker, 6A	COTS	2
4	XYZ	Power Supply 24VDC, 3-Phase	COTS	2
4	XYZ	Redundancy Module	COTS	1
4	XYZ	Miniature Circuit Breaker, 20A	COTS	1
4	XYZ	Miniature Circuit Breaker, 1+N-pole, 4A	COTS	1
4	XYZ	Power Supply 12VDC, 1-Phase, 1.5A	COTS	1
4	XYZ	Motor Protection Switch	COTS	1
4	XYZ	Varistor, S00	COTS	2
4	XYZ	Power Contactor, 3kW	COTS	2
4	XYZ	Solid State Relay, 1NO	COTS	1
4	XYZ	Coupling Relay, 24V, 6A	COTS	1
4	316-061xxx	Terminal Block (XLP IO)	Develop	1
5	XYZ	End Clamp 35-5	COTS	1
5	XYZ	Terminal Block Marker	COTS	1
5	XYZ	End Cover D-ST 2.5-Twin	COTS	1
5	XYZ	Through terminal	COTS	1
4	316-061xxx	Terminal Block (XLM IO)	Develop	1
5	XYZ	End Clamp 35-5	COTS	1
5	XYZ	Terminal Block Marker	COTS	1
5	XYZ	End Cover D-ST 2.5-Twin	COTS	1
5	XYZ	Through terminal	COTS	1
4	316-061xxx	Terminal Block (XLP AUX)	Develop	1
5	XYZ	End Clamp 35-5	COTS	1
5	XYZ	Terminal Block Marker	COTS	1
5	XYZ	End Cover D-ST 2.5-Twin	COTS	1
5	XYZ	Through terminal	COTS	1
4	316-061xxx	Terminal Block (XLM AUX)	Develop	1
5	XYZ	End Clamp 35-5	COTS	1

DS Level	Identifier	Description	Type	Quantity
5	XYZ	Terminal Block Marker	COTS	1
5	XYZ	End Cover D-ST 2.5-Twin	COTS	1
5	XYZ	Through terminal	COTS	1
4	XYZ	Miniature Circuit Breaker, 3-pole, 400V, 25A	COTS	1
4	XYZ	Miniature Circuit Breaker, 3-pole, 400V, 25A	COTS	1
4	XYZ	Miniature Circuit Breaker, 3-pole, 400V, 25A	COTS	1
4	XYZ	Surge suppressor, size S0	COTS	1
4	XYZ	Auxiliary Contact Block, 2NO/2NC	COTS	1
4	XYZ	Auxiliary Contactor, 24VDC, 4NO	COTS	1
4	XYZ	Surge suppressor, size S0	COTS	1
4	XYZ	Auxiliary Contact Block, 2NO/2NC	COTS	1
4	XYZ	Auxiliary Contactor, 24VDC, 4NO	COTS	1
4	XYZ	Surge suppressor, size S0	COTS	1
4	XYZ	Auxiliary Contact Block, 2NO/2NC	COTS	1
4	XYZ	Auxiliary Contactor, 24VDC, 4NO	COTS	1
4	XYZ	Circuit Breaker, 1-pole, B, 6A	COTS	1
4	XYZ	Circuit Breaker, 1-pole, B, 6A	COTS	1
4	XYZ	Circuit Breaker, 1-pole, B, 10A	COTS	1
4	XYZ	Circuit Breaker, 1-pole, B, 6A	COTS	1
4	XYZ	Circuit Breaker, 1-pole, B, 6A	COTS	1
4	XYZ	Circuit Breaker, 1-pole, B, 6A	COTS	1
4	XYZ	Circuit Breaker, 1-pole, B, 6A	COTS	1
4	XYZ	Circuit Breaker, TBD	COTS	1
4	316-061xxx	Terminal Blok (XLP Power)	Develop	1
5	XYZ	End Clamp 35-5	COTS	1
5	XYZ	Terminal Block Marker	COTS	1
5	XYZ	End Cover D-ST 2.5-Twin	COTS	1
5	XYZ	Through terminal	COTS	5
4	316-061xxx	Terminal Blok (XLM Power)	Develop	1
5	XYZ	End Clamp 35-5	COTS	1
5	XYZ	Terminal Block Marker	COTS	1
5	XYZ	End Cover D-ST 2.5-Twin	COTS	1
5	XYZ	Through terminal	COTS	11
4	316-061xxx	Terminal Blok (XLP Servo)	Develop	1
5	XYZ	End Clamp 35-5	COTS	1
5	XYZ	Terminal Block Marker	COTS	1
5	XYZ	End Cover D-ST 2.5-Twin	COTS	1
5	XYZ	Through terminal	COTS	3
4	XYZ	Main Contactor, 3kW, 24VDC, 2NC/2NO	COTS	1
4	XYZ	Through terminal	COTS	3
4	XYZ	Circuit Breaker 3-pole, C, 63A	COTS	1
4	XYZ	?	COTS	1
4	XYZ	Main / Emergency Stop Switch, 3-pole, 160A	COTS	1
4	XYZ	Switching element N-conductor 160A	COTS	1
4	XYZ	Room combined sensor 2x(0-10V)	COTS	1
4	XYZ	Enclosure internal thermostat	COTS	1
4	XYZ	Ethernet switch, 8-port	COTS	1
4	XYZ	Drive Cabinet Wiring set	COTS	ar
4	316-061xxx	EMI filter set	Develop	1
3	316-061000	Azimuth IO Unit Installation	Develop	1
4	316-061xxx	Azimuth IO Unit	Develop	1
5	XYZ	Main Axis Angular Encoder	COTS	1
5	316-061xxx	Azimuth IO module	Develop	1
6	XYZ	EtherCAT Coupler	COTS	1
6	XYZ	EtherCAT Terminal - field supply	COTS	1
6	XYZ	EtherCAT Terminal - 2-channel analog input	COTS	1
6	XYZ	EtherCAT Terminal - 16-channel digital input	COTS	1
6	XYZ	EtherCAT Terminal - 4-channel digital input, TwinSAFE	COTS	1
6	XYZ	EtherCAT Terminal - 2-channel EnDat2.2 interface	COTS	1
6	XYZ	Endcap	COTS	1
5	XYZ	EMI Filter - Azimuth IO Unit	COTS	1
5	XYZ	Main Axis Limit switches	COTS	5
5	XYZ	Temperture & Humidity sensor	COTS	1
5	316-061xxx	Azimuth IO Unit EMI-Gasket 1	Develop	n
5	316-061xxx	Azimuth IO Unit EMI-Gasket 2	Develop	n
5	XYZ	Azimuth IO Unit Ball-seal	COTS	1
5	316-061xxx	EMI Enclosure & internal mechanics	Develop	1
4	316-061xxx	Shaft end	Develop	1
4	316-061xxx	Shaft end	Develop	1

DS Level	Identifier	Description	Type	Quantity
4	316-061xxx	Shaft Coupling	Develop	1
4	316-061xxx	Adaptor	Develop	1
3	316-061500	Elevation IO Unit Installation	Develop	1
4	316-0615xx	Elevation IO Unit	Develop	1
5	XYZ	Main Axis Angular Encoder	COTS	1
5	316-0615xx	Elevation IO module	Develop	1
6	XYZ	EtherCAT Coupler	COTS	1
6	XYZ	EtherCAT Terminal - field supply	COTS	1
6	XYZ	EtherCAT Terminal - 2-channel analog input	COTS	1
6	XYZ	EtherCAT Terminal - 16-channel digital input	COTS	1
6	XYZ	EtherCAT Terminal - 2-channel digital output	COTS	1
6	XYZ	EtherCAT Terminal - 4-channel digital input, TwinSAFE	COTS	1
6	XYZ	EtherCAT Terminal - 2-channel EnDat2.2 interface	COTS	1
6	XYZ	Endcap	COTS	1
5	XYZ	EMI Filter - Elevation IO Unit	COTS	1
5	XYZ	Limit switches	COTS	4
5	XYZ	Temperture & Humidity sensor	COTS	1
5	316-0615xx	Elevation IO Unit EMI-Gasket 1	Develop	1
5	316-0615xx	Elevation IO Unit EMI-Gasket 2	Develop	1
5	316-0615xx	Elevation IO Unit Ball-seal	COTS	1
5	316-0615xx	Elevation IO Unit Enclosure & mechanics	Develop	1
4	316-0615xx	Elevation IO Unit Cover	Develop	1
4	316-0615xx	Shaft Coupling 1	Develop	1
4	316-0615xx	Shaft Coupling 2	Develop	1
4	316-0615xx	Shaft	Develop	1
3	316-062000	Feed Indexer IO Unit	Develop	1
4	XYZ	Feed Indexer Encoder	COTS	1
4	XYZ	Encoder Bearing Unit	COTS	1
4	316-062xxx	Feed Indexer IO module	COTS	1
5	XYZ	EtherCAT Coupler	COTS	1
5	XYZ	EtherCAT Terminal - field supply	COTS	1
5	XYZ	EtherCAT Terminal - 2-channel analog input	COTS	1
5	XYZ	EtherCAT Terminal - 16-channel digital input	COTS	1
5	XYZ	EtherCAT Terminal - 2-channel digital output	COTS	1
5	XYZ	EtherCAT Terminal - 4-channel digital input, TwinSAFE	COTS	2
5	XYZ	EtherCAT Terminal - 2-channel EnDat2.2 interface	COTS	1
5	XYZ	Endcap	COTS	1
4	XYZ	Temperture & Humidity sensor	COTS	1
4	XYZ	EMI Filter - Feed Indexer IO Unit	COTS	1
4	316-062xxx	Feed Indexer IO Unit Enclosure & internal mechanics	Develop	1
5	316-062xxx	Upper Encoder Mounting Box	Develop	1
5	316-062xxx	Encoder Lower Cover Assy	Develop	1
5	316-062xxx	Emi Gasket R 10	COTS	1
5	316-062xxx	Electronics Support	Develop	1
5	316-062xxx	EMI Gasket R 82,5	COTS	1
5	316-062xxx	Filter Box Bracket Assy	Develop	1
5	316-062xxx	Electronics Support Bracket	Develop	1
4	316-062xxx	Encoder pinion axis	Develop	1
4	316-062xxx	Encoder pinion	Develop	1
3	316-062500	Azimuth Main Drive Actuator	Develop	1
4	XYZ	Azimuth Motor	COTS	2
4	XYZ	Azimuth Gearbox	COTS	2
4	316-062xxx	Azimuth Drive Pinion	Develop	2
4	XYZ	Azimuth Motor shaft coupling	COTS	2
3	316-063000	Elevation Main Drive Actuator	Develop	1
4	316-063xxx	Bellows	COTS	1
3	316-063500	Feed Indexer Drive Actuator	Develop	2
4	XYZ	Feed Indexer Motor	COTS	1
4	XYZ	Feed Indexer Gearbox	COTS	1
4	XYZ	Feed Indexer Drive Pinion	COTS	1
3	316-064000	Tiltmeter Installation	COTS	1
4	XYZ	Tiltmeter	COTS	1
4	316-064xxx	Tiltmeter Cover	Develop	1
3	316-068000	Ambient Temperature Sensor Installation	COTS	3
4	XYZ	Ambient Temperature Sensor	COTS	3
4	316-068xxx	Bracket & Cover 1	Develop	1
4	316-068xxx	Bracket & Cover 2	Develop	2
3	316-064500	Warning Horn & Safety Light	COTS	1
4	XYZ	Siren	COTS	1

DS Level	Identifier	Description	Type	Quantity
4	XYZ	Beacon	COTS	1
3	316-065000	User Interface Panel	Develop	1
4	XYZ	Enclosure (600x200x120)	COTS	1
4	XYZ	Load Disconnector	COTS	3
4	XYZ	Emergency Stop Push Button with Lock	COTS	1
4	XYZ	Emergency Stop, Plain Shield, Round, Yellow	COTS	1
4	XYZ	Emergency Stop, Switch element	COTS	1
4	XYZ	Connector Panel Mount	COTS	1
4	XYZ	Connector Insert	COTS	1
3	316-065500	Power Monitor & Control set	Develop	1
4	XYZ	Current transformer	COTS	1
3	316-066000	Control System Cable set	Develop	1
3	316-066500	Ventilation Air Temperature & Humidity Sensor set	Develop	1
4	XYZ	Air Temperature & Humidity Sensor	COTS	3
3	316-067000	Door Open/Close Sensor set	Develop	1
4	XYZ	Position switch with actuator and roller lever	COTS	3
3	316-067500	Feed Indexer Ancillary set	Develop	1
4	XYZ	Feed Indexer Limit Switches	COTS	2
4	XYZ	Feed Indexer Emergency Stop	COTS	1
3	316-05xxxx	Azimuth Stow Lock Installation	Develop	1
4	XYZ	Transmission	COTS	1
4	316-05xxxx	Mechanical structure incl Locking pin …	Develop	1
4	XYZ	Grease nipple	COTS	1
4	XYZ	Motor	COTS	1
4	XYZ	Limit switch	COTS	2
2	316-070000	DS Support Equipment	Develop	1

6.4 Appendix: SKA Dish PSC Ventilation Simulation

6.4.1 Theoretical Calculation

6.4.1.1 Heat loads

The main thermal source inside the PSC is the EMISC, Drive cabinet, UPS and ventilation fans. The heat loads are as followed:

- **EMISC: 1000W/s**
- **Drive Cabinet: 1000W/s**
- **UPS: 1000W/s**
- **Fans: 83X4=332W/s**
- **Total: 3132W/s**

The solar heating is another main factor that increases the temperature inside the pedestal. Considering the noon time, local longitude and latitude, the solar heat is calculated as 1020W/(m^2·s). The solar altitude in January is 75˚. The degraded reflecting ratio of the white paint on the wall is set as 0.5. The ratio of the additional ground reflecting effect is set as 0.2. The overall heat load from the solar is estimated as 1466W/s. The effort of using sunshield cover has not been taken into consideration to allow more safety factor.
Thus the total heat load on the PSC is 4598W/s.

6.4.1.2 Vents

The EBM PAPST W2E 250-HL06-01 is selected as the ventilation fan, of which the pressure diagram is shown in Figure 310. The curve of step1 is applied. Considering the pressure drop of the air filter, the point 8 is taken into the calculation, where the airflow is 950 m^3/h (0.264m^3/s).

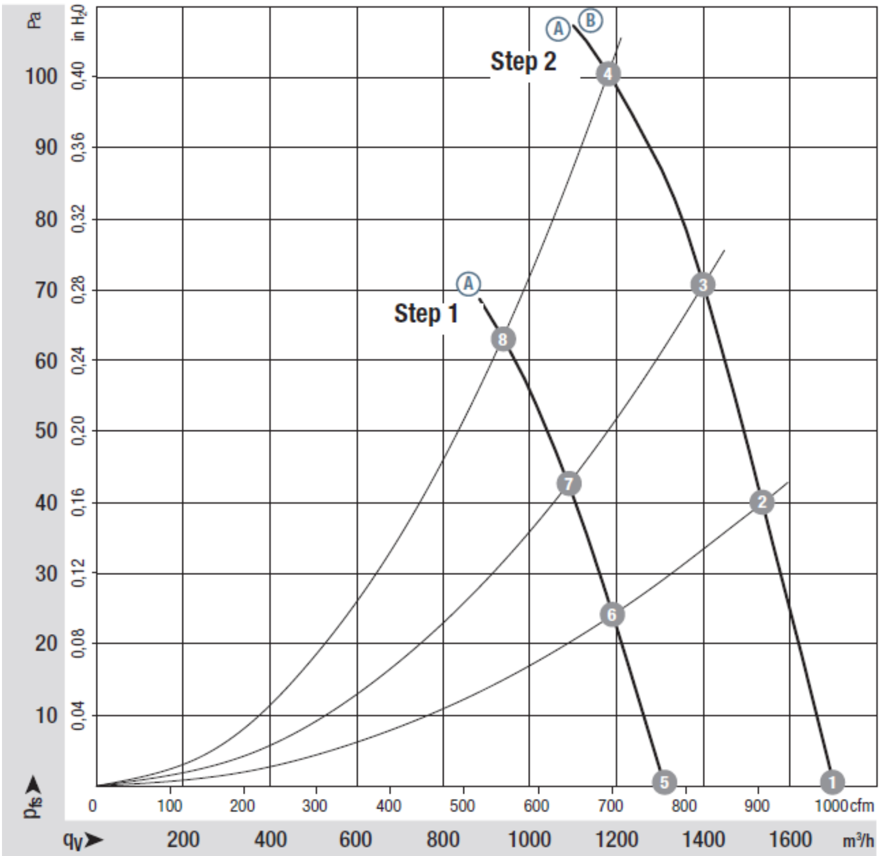


Figure 310: Pressure Diagram of the Fans

With two vents working together, the transferred heat load of 10˚C increased temperature is expected as 6831.6J. The heat transferring capacity of the vents is higher than the heat load, which means that the ventilation system can meet the requirement.

6.4.2 Computational Simulation

6.4.2.1 Model setup

Ambient Temperature: 40˚C, no wind, no cloud

The geometry model is based on a real model as shown in Figure 311. The heat sources are shown as red parts. The inner structure of cabinet is simplified for pedestal shielded compartment thermal analysis.

The wind channel is assumed as vertical where heat resources are located. The positions and sizes of inlet and outlet vents are based on actual model.

The model of vent is based on the actual model. According to the specification of the wave-guide vent, the pressure drop is about 30% when the wind speed is 3 ~ 4 m/s.

The airdrop is considered for the vents. The resistance type and free area ratio is set in the model, as shown in Figure 312.

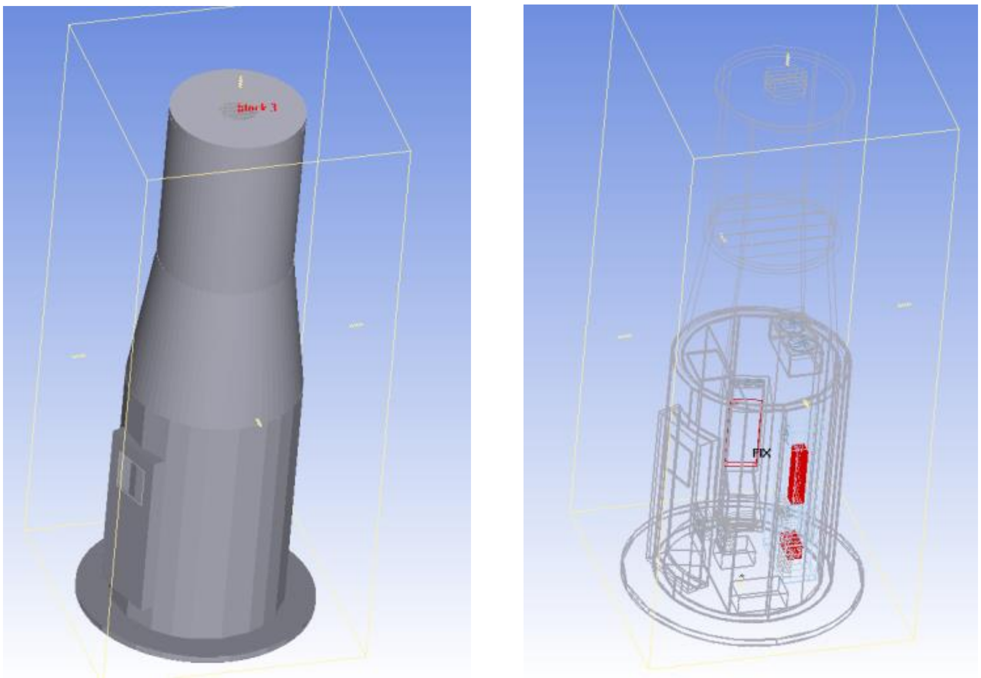


Figure 311: Geometry Model of the Pedestal

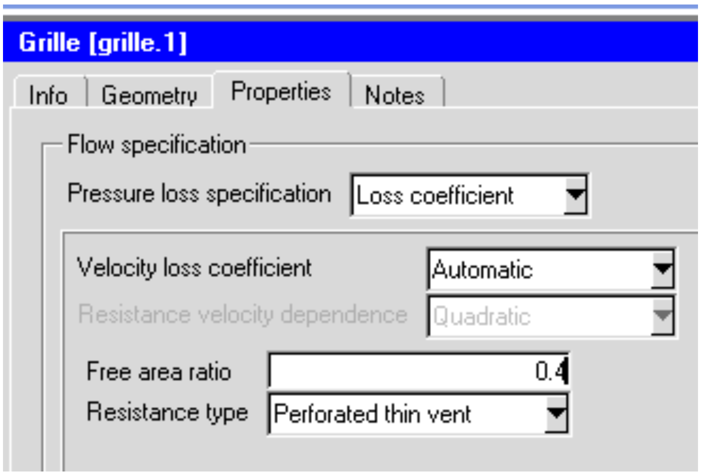


Figure 312: Vent Grille Setup

The solar radiation is generated in the simulation. The longitude and latitude of the site geography location are input to the analysis. The hottest month and the noon time are selected. The ground reflection coefficient is set as 0.2 and the clear sky is assumed. The positive X-axis direction is set towards true north. These parameters are input to the analysis system and will be calculated automatically, as shown in Figure 313.

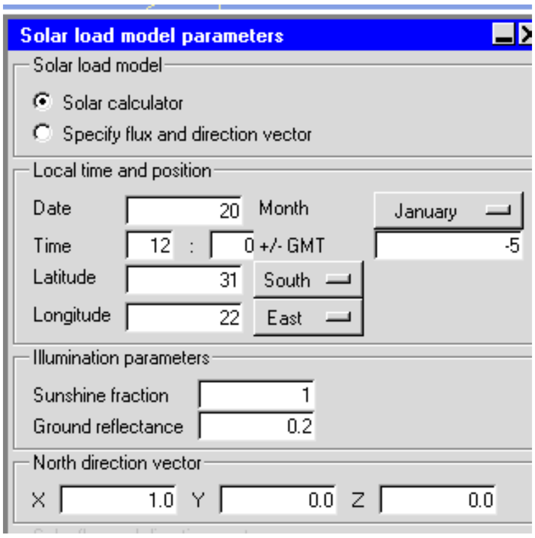


Figure 313: Solar Load Model Parameters

Heat Resource:

EMISC 1000w/s
UPS 1500 W/s
Servo 1000 W/s

Scenario Setup:

The EMISC is equipped with 3*dia.150mm outlet fans. The servo cabinet is equipped with 1*dia.300mm outlet fan. The UPS is equipped with 2*dia.200mm outlet fans.
The PSC is equipped with 2*dia.250mm inlet fans and 2*dia.250mm outlet fans.

6.4.2.2 Sunshield Cover

The temperature distribution on the outer surface of the pedestal is shown in Figure 314. The highest
temperature is about 66℃ at the sunshield in the direction against the sunlight.

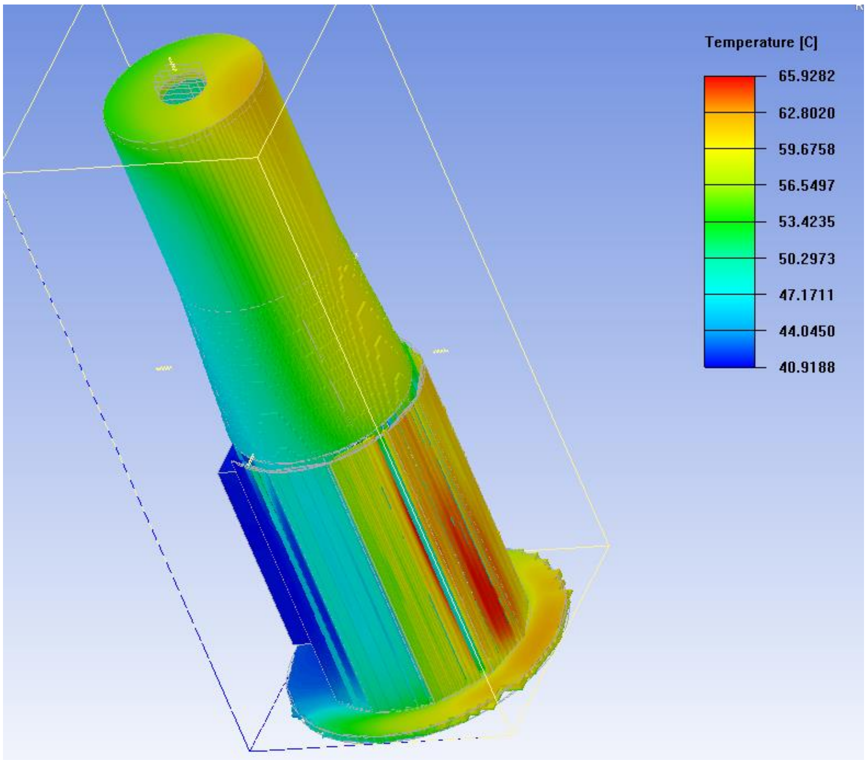


Figure 314: Temperature Distribution on the Outer Surface of the Pedestal

As shown in Figure 315, the temperature on the inner wall of the PSC is lower than that on the sunshield cover by 7~10 ˚C. The sunshield cover can effectively protect the temperature condition inside the PSC against the heating of solar.

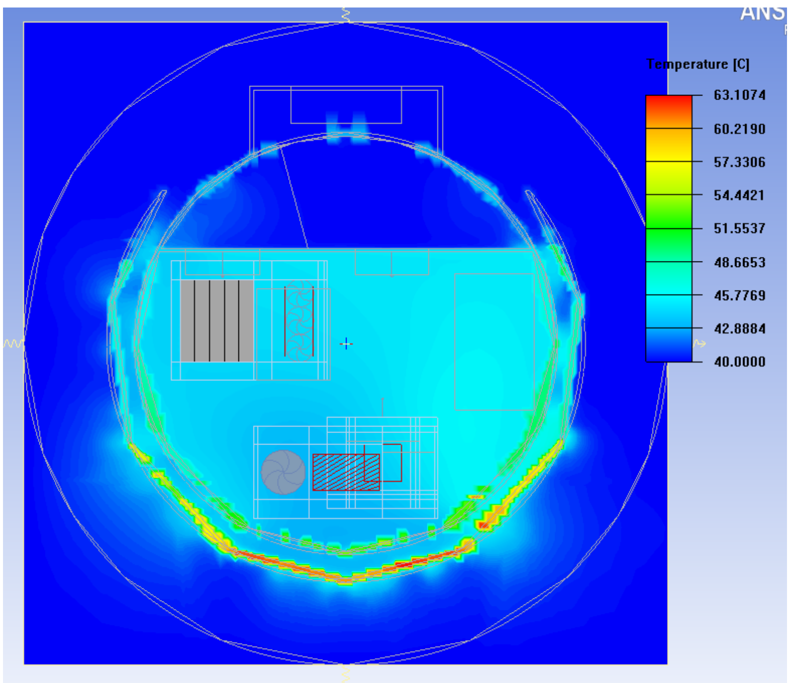


Figure 315: Temperature Distribution on Horizontal Section of the Pedestal

6.4.2.3 Cabinets

The temperature around the EMISC and EMIDC are mostly in the range from 43℃ to 45℃ as shown in Figure 316.

The temperature around UPS drive cabinet is about 47~50℃. This is mainly due to the heat conduction from the pedestal wall.

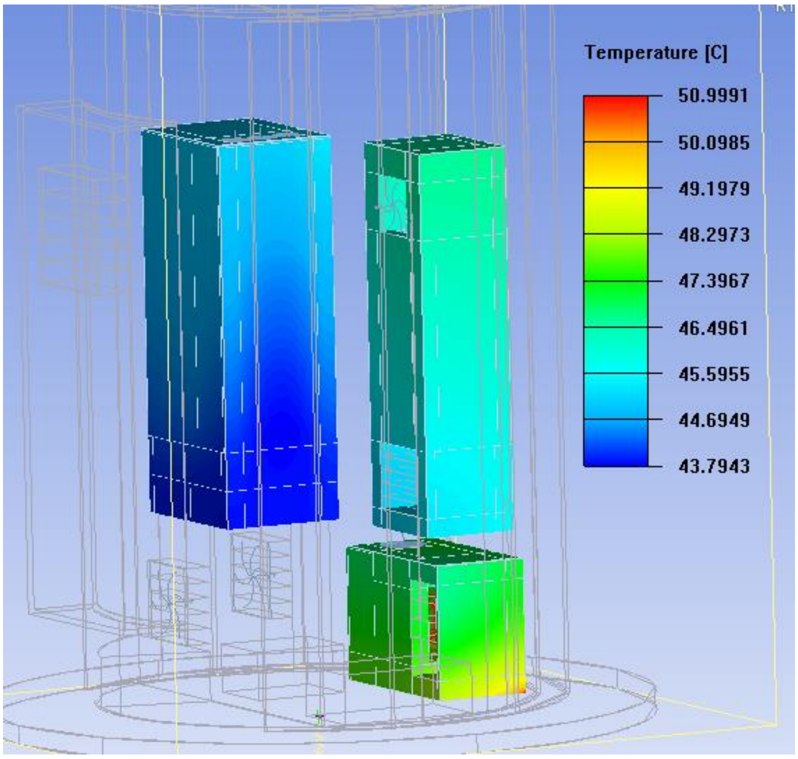


Figure 316: Temperature surrounding the cabinets

6.4.2.4 Vents

As shown in Figure 317, the temperatures at inlet and outlet vents show that the overall airflow is good. The outlet temperature of PSC is about 45℃. The inlet temperature of PSC is about 40℃. The inlet temperatures of three cabinets are about 40~42℃.

The outlet temperature of EMIDC indicates that the ventilation system can be optimized further by enhancing the outlet vent of the drive cabinet.

The air speeds at the vents indicate that the pressure drop occurs at the air filter as expected, as shown in Figure 318 and Figure 319.

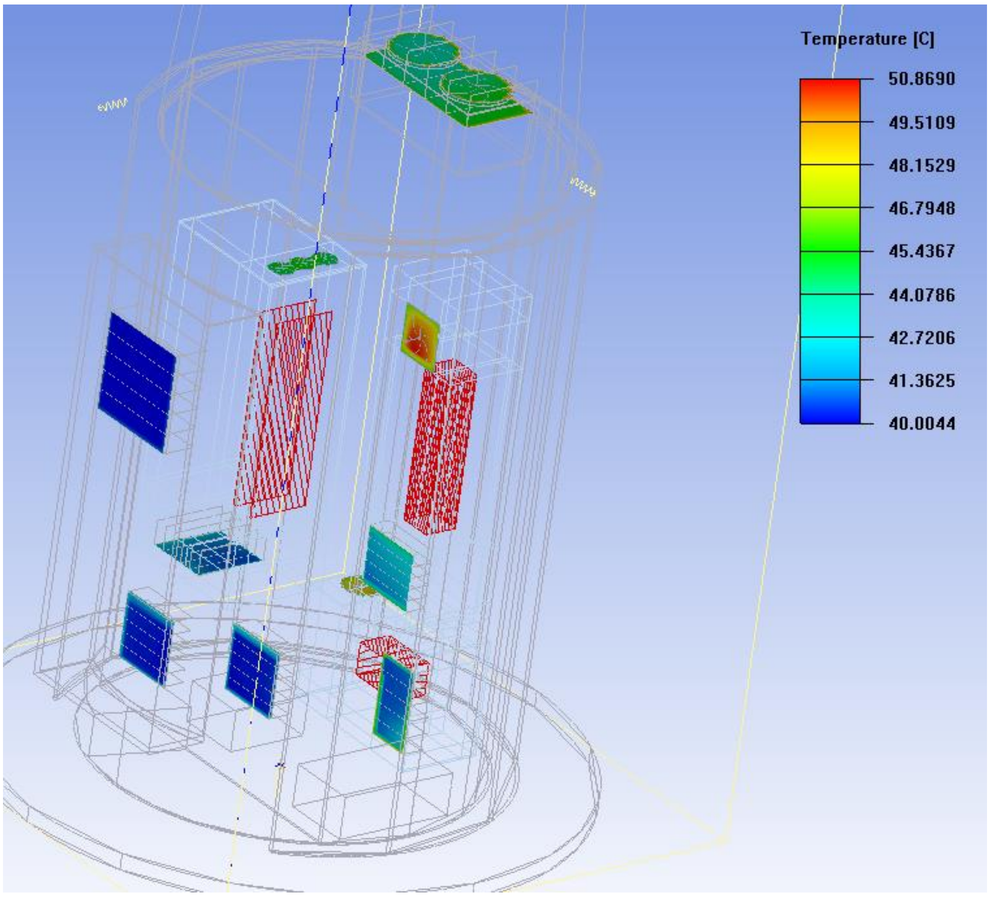


Figure 317: Temperature Distribution on the Vents of the Pedestal

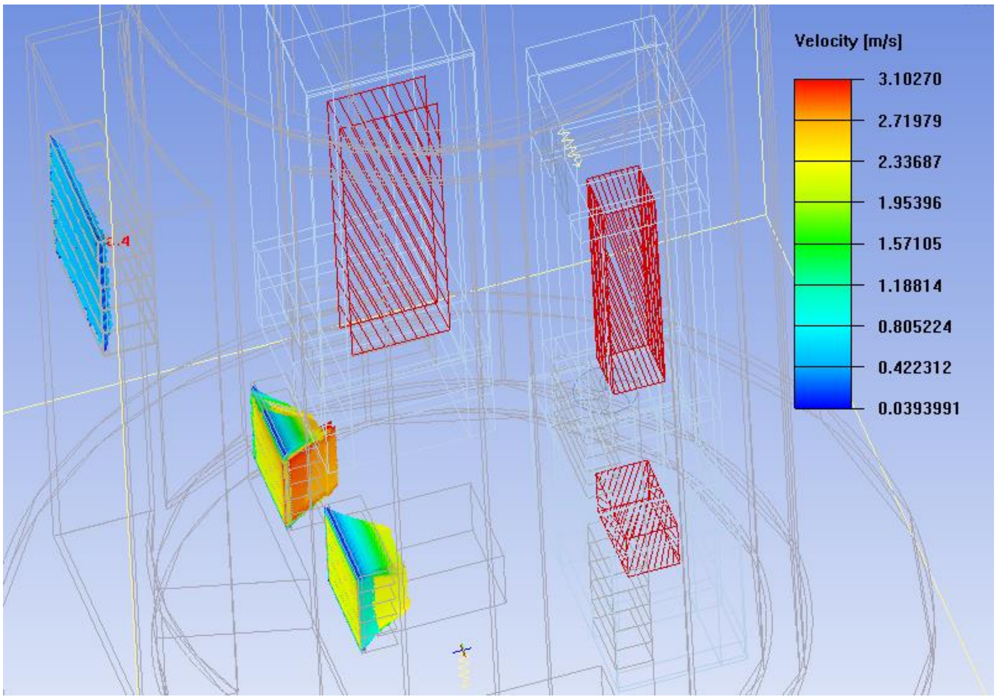


Figure 318: Airflow Speed on the Vents

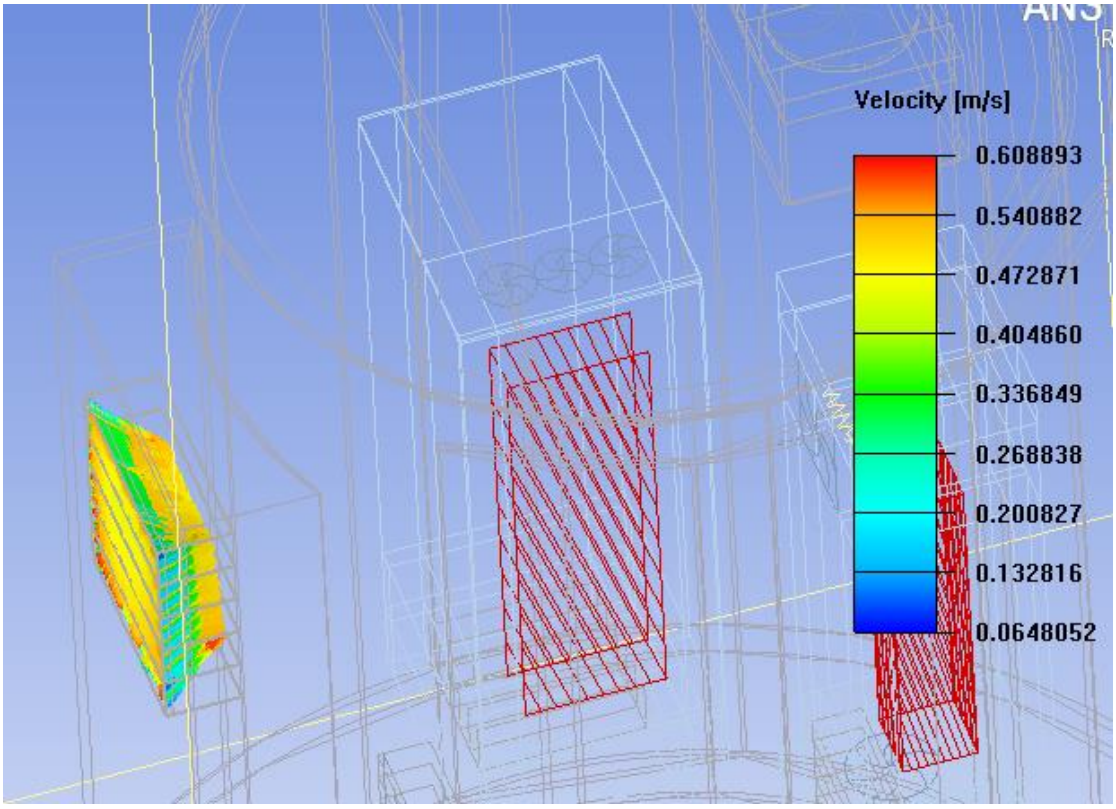


Figure 319: Airflow Speed on the Pedestal Door Vents

6.4.2.5 Airflow

The airflow in the pedestal is shown in Figure 320. The flow path shows that there is little turbulence from the pedestal door to the outlet vents of the PSC. The temperature distribution along the airflow path indicates that the ventilation system can remove the hot air outside the PSC effectively.

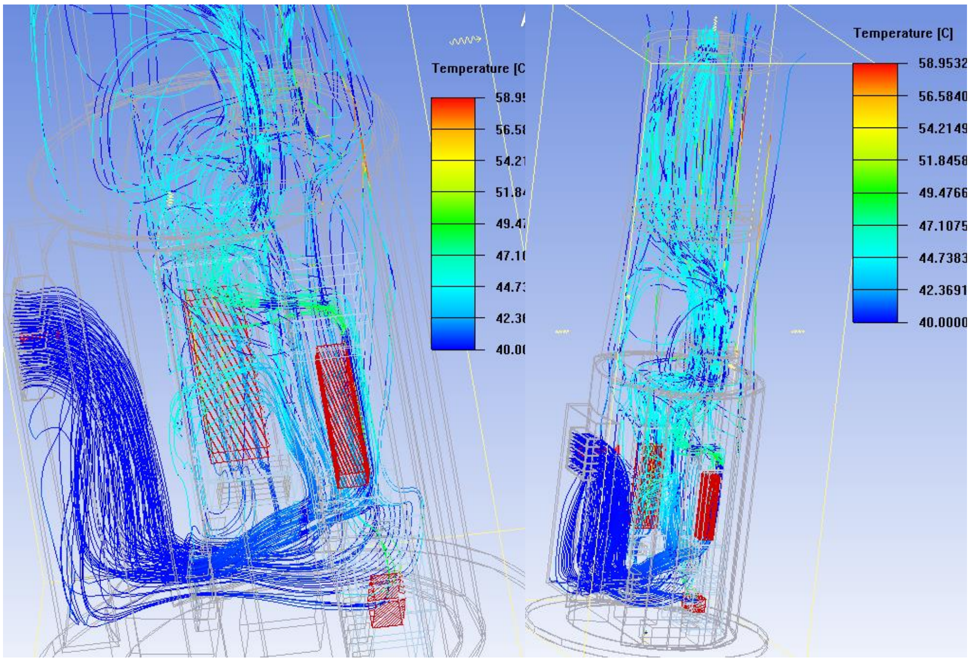


Figure 320: Airflow in Pedestal

6.4.3 Results

Both theoretical calculation and computational simulation indicate that the ventilation system of the PSC is sufficient for the given heat load and required environmental condition. The layout of the vent and the cabinets can provide efficient airflow. The capacity of the vent fans can meet the requirement.
It is noted that the UPS cabinet, as one proposed solution, has been considered in the analysis. The total heat load should be enough for the practical conditions.
Noted that, since the time the simulation were performed, the orientation of the air outlet for the Drive Cabinet has changed to the roof of the cabinet blowing the hot air upwards – this will further improve the airflow and turbulence inside the PSC.


DISH STRUCTURE DETAIL DESIGN DOCUMENT

316-000000-022 DS Design Document approval page

Adobe Sign Document History 12/10/2018

Created:	10/10/2018
By:	Alastir Robyntjies (cms@ska.ac.za)
Status:	Signed
Transaction ID:	CBJCHBCAABAAHoM-lzl3CS5_kT4QhnUxNQcoiGdPcW0d

"316-000000-022 DS Design Document approval page" History

Document created by Alastir Robyntjies (cms@ska.ac.za)
10/10/2018 - 14:59:10 GMT+2- IP address: 196.24.39.242

Document emailed to Henk Niehaus (henk@ska.ac.za) for signature
10/10/2018 - 15:00:37 GMT+2

Document viewed by Henk Niehaus (henk@ska.ac.za)
10/10/2018 - 15:01:55 GMT+2- IP address: 196.24.39.242

Document e-signed by Henk Niehaus (henk@ska.ac.za)
Signature Date: 10/10/2018 - 15:02:21 GMT+2 - Time Source: server- IP address: 196.24.39.242

Document emailed to Renato Aurigemma (r.aurigemma@samaerospazio.it) for signature
10/10/2018 - 15:02:21 GMT+2

Document viewed by Renato Aurigemma (r.aurigemma@samaerospazio.it)
10/10/2018 - 15:55:59 GMT+2- IP address: 79.1.41.26

Document e-signed by Renato Aurigemma (r.aurigemma@samaerospazio.it)
Signature Date: 10/10/2018 - 15:56:58 GMT+2 - Time Source: server- IP address: 79.1.41.26

Document emailed to Du Biao (biaodu@163.com) for signature
10/10/2018 - 15:56:58 GMT+2

Document viewed by Du Biao (biaodu@163.com)
12/10/2018 - 07:48:08 GMT+2- IP address: 121.28.24.235

Document e-signed by Du Biao (biaodu@163.com)
Signature Date: 12/10/2018 - 11:26:47 GMT+2 - Time Source: server- IP address: 121.28.24.235

Document emailed to Lutz Stenvers (lutz.stenvers@mt-mechatronics.de) for signature
12/10/2018 - 11:26:47 GMT+2

Document viewed by Lutz Stenvers (lutz.stenvers@mt-mechatronics.de)

12/10/2018 - 11:55:35 GMT+2- IP address: 212.118.198.36

Document e-signed by Lutz Stenvers (lutz.stenvers@mt-mechatronics.de)

Signature Date: 12/10/2018 - 11:56:02 GMT+2 - Time Source: server- IP address: 212.118.198.36

Document emailed to WANG, Feng (wangfeng.ska@outlook.com) for signature

12/10/2018 - 11:56:02 GMT+2

Document viewed by WANG, Feng (wangfeng.ska@outlook.com)

12/10/2018 - 15:12:25 GMT+2- IP address: 223.104.13.40

Document e-signed by WANG, Feng (wangfeng.ska@outlook.com)

Signature Date: 12/10/2018 - 16:49:18 GMT+2 - Time Source: server- IP address: 221.194.6.202

Signed document emailed to WANG, Feng (wangfeng.ska@outlook.com), Alastir Robyntjies (cms@ska.ac.za), Renato Aurigemma (r.aurigemma@samaerospazio.it), Lutz Stenvers (lutz.stenvers@mt-mechatronics.de) and 2 more

12/10/2018 - 16:49:18 GMT+2