MeerKAT Receptor as SKA candidate

Penticton Receptor CoDR, July 2011

LJ du Toit, EMSS Antennas (pp. NRF, South Africa)
Willem Esterhuyse, Project Manager, MeerKAT project

Coming soon to Carnarvon…

Contents

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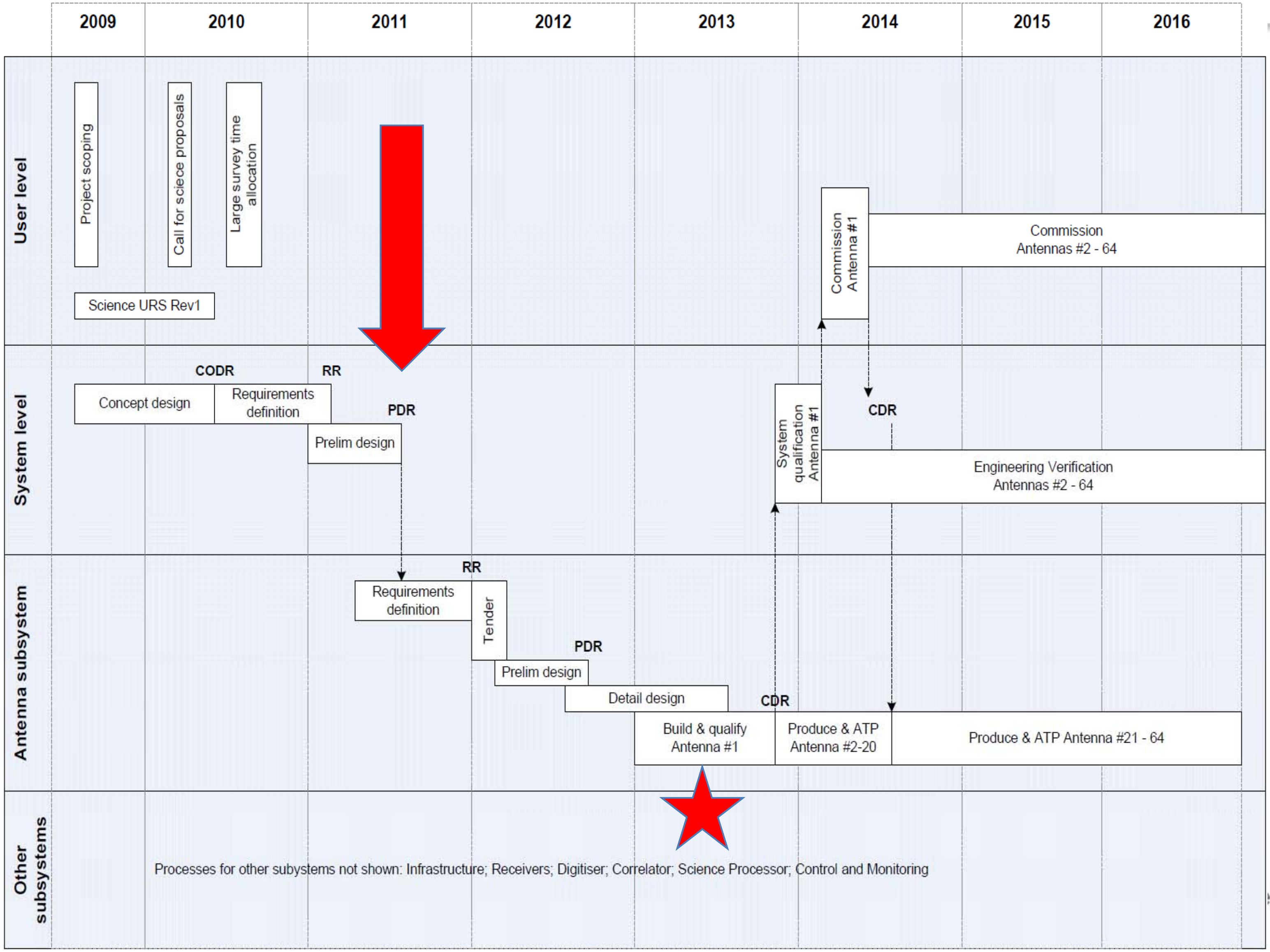
- MeerKAT receptor → SKA candidate?
- Random walk through …
  - Structure
  - Reflector
  - Optics
  - Receivers
  - RF & digitization

Context – In Time



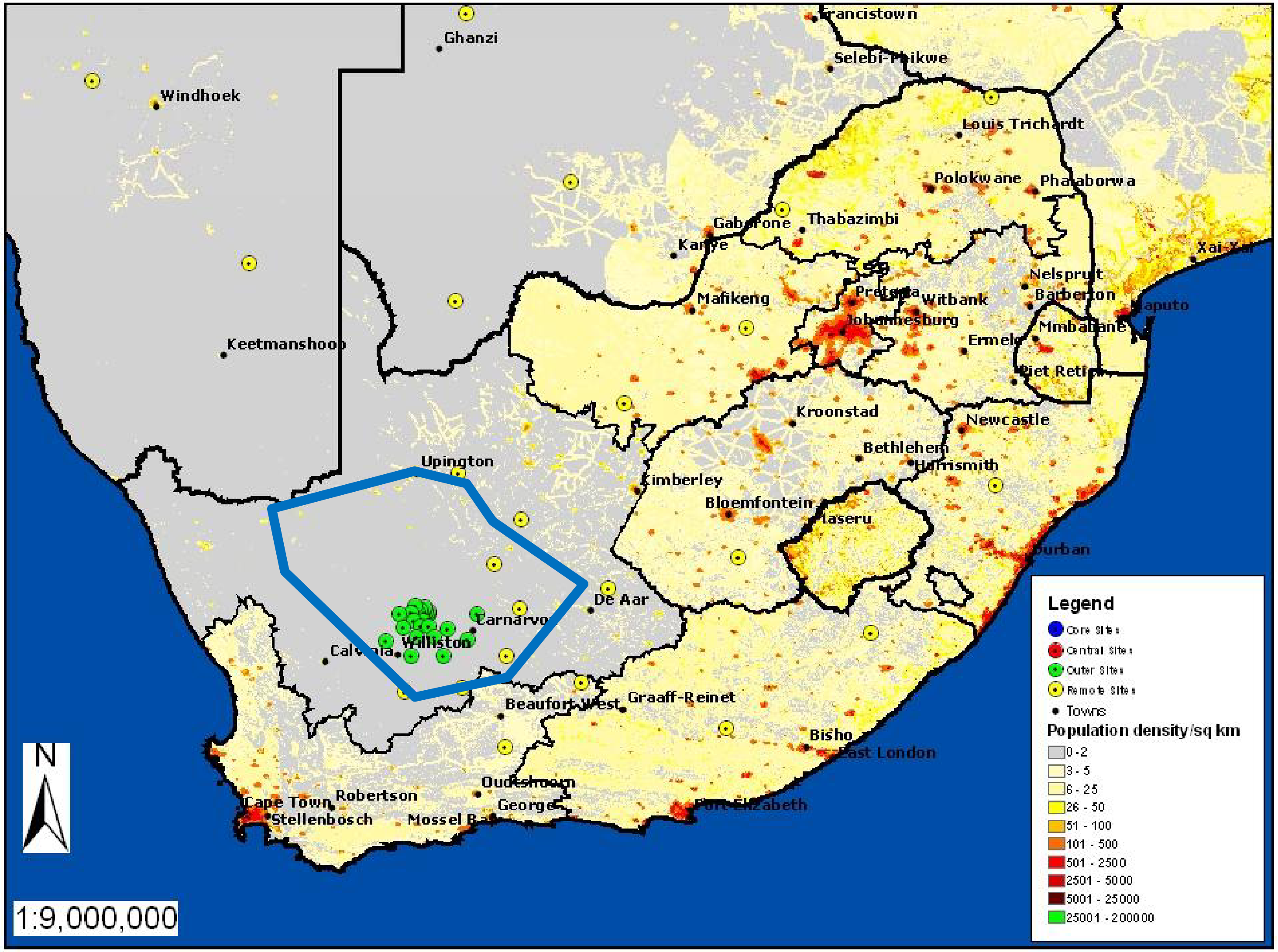
lescope

Context – In Relevance

As precursor, the MeerKAT schedule requires timely decisions, which may be different from those made by SKA

The decision processes may thus be more relevant than the outcomes

Context – Geographical



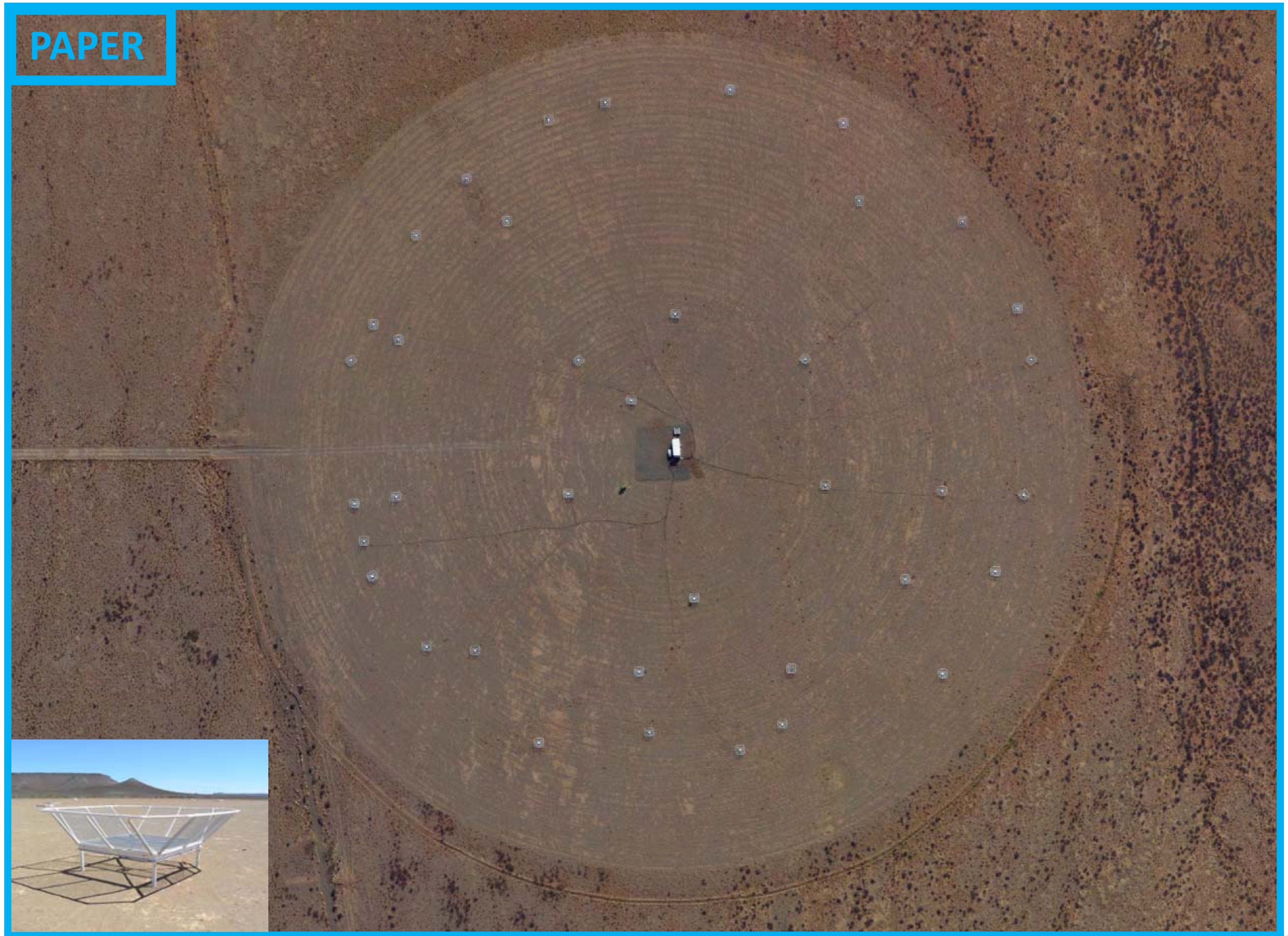
telescope

Context – Geographical

's largest radio telescope

Context – Geographical

Context – Geographical



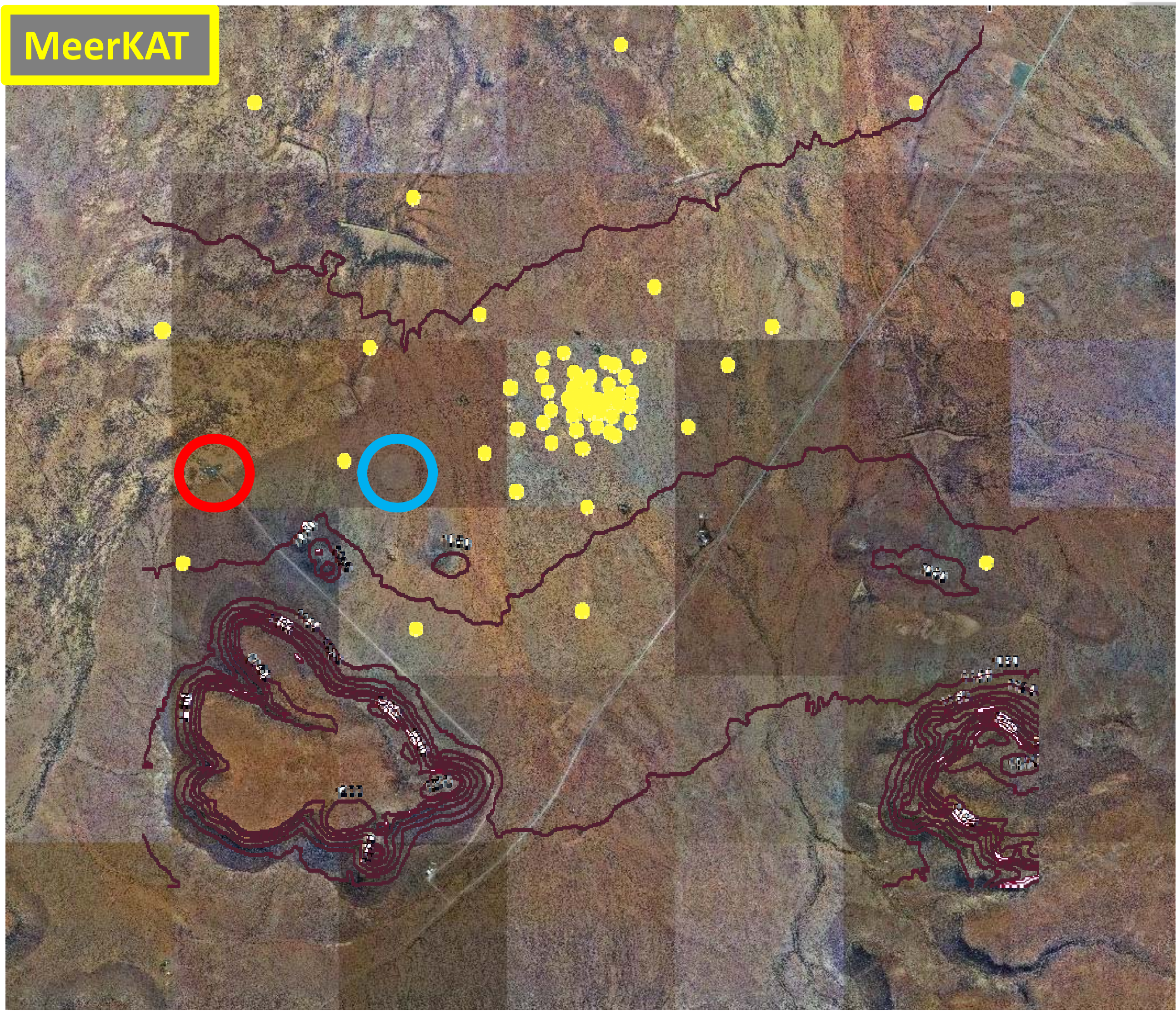
Context – Geographical

s largest radio telescope

Context – Geographical

elescope

Context – Geographical



's largest radio telescope

Context – In Frequency

	Phase 1 (current planning)	Phase 2
Estimated completion date	2016	2018
Frequency bands (GHz)	1-1.75	0.58 – 1.015 8-14.5
RF bandwidth (MHz)	850	6500
Sampling frequency (GSPS)	5	30
Processed bandwidth (MHz)	850	6500
Max baseline (km)	10	10

Context – In science

- International RFP in 2009
  - 21 major proposals received by the March 2010 deadline (about 500 international scientists from more than 80 institutions and 20 countries self-organized to produce these proposals.)
- All proposals closely related to SKA science, all use unique features that MeerKAT offers.
- Adjudication September 2010 (international panel)
  - 2 Priority 1 surveys:
    - Study of the origin and evolution of galaxies.
    - Study of Einstein's theory of gravity and fundamental physics.
    - Same as the two SKA Phase-1 science drivers.
- 8 Priority 2 surveys and other "unsuccessful" proposals.
  - Excellent science that uses unique features of MeerKAT.
  - Aspects of other surveys considered for smaller time allocations.
- Work session of PIs in Cape Town in April 2011

Context – In science
MeerKAT Large Survey PIs (17-18 April 2011)

Formal interaction with MeerKAT system engineers to unpack survey proposals into science requirements and MeerKAT system specification

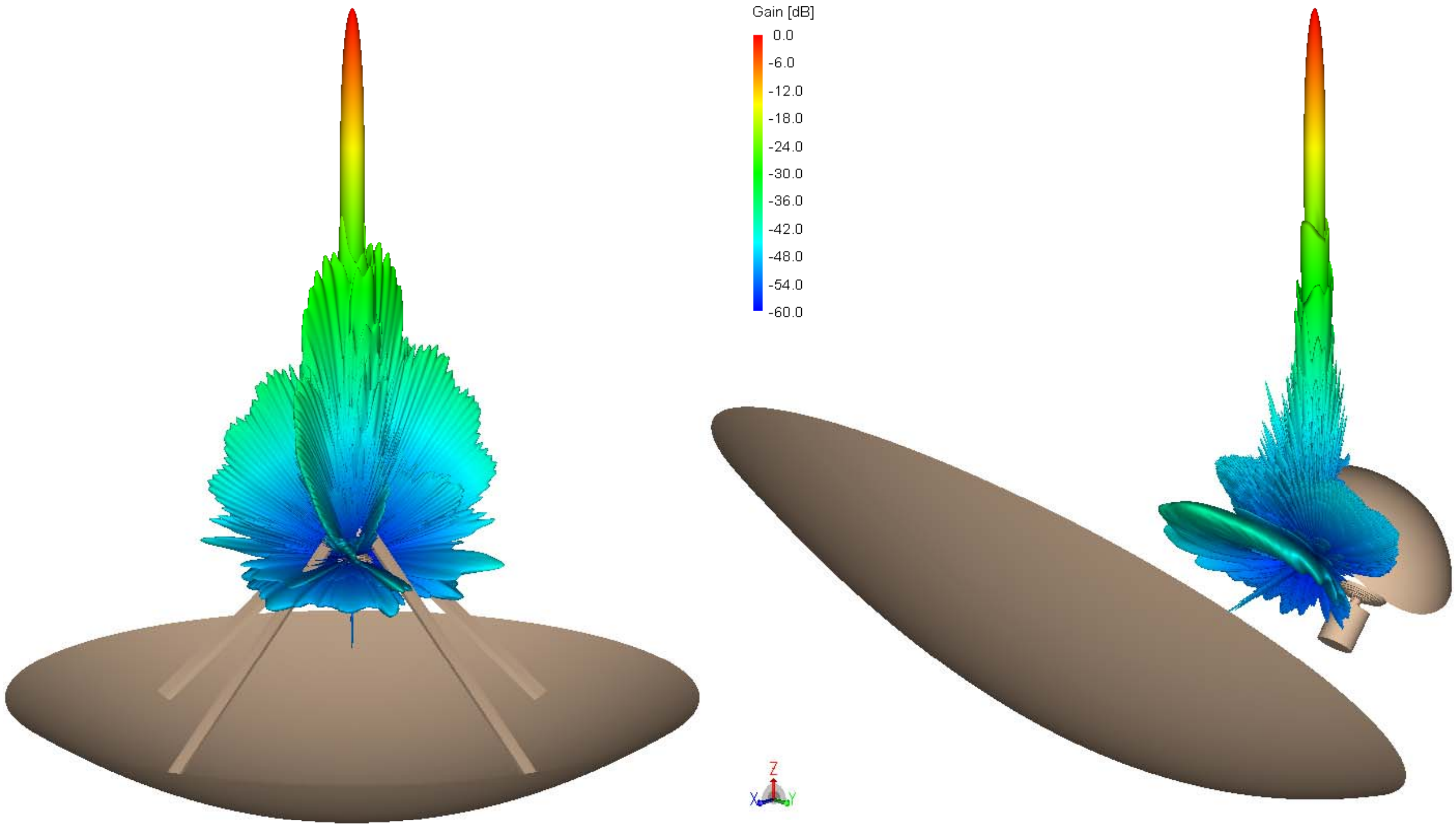
Context –Science linked to SE

MeerKAT approved documents

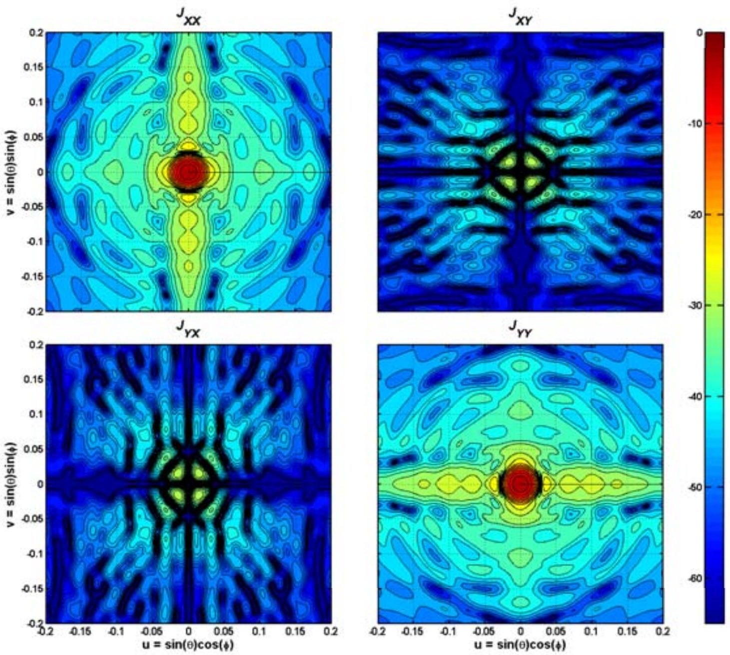
Context – In A_e/T_{sys}

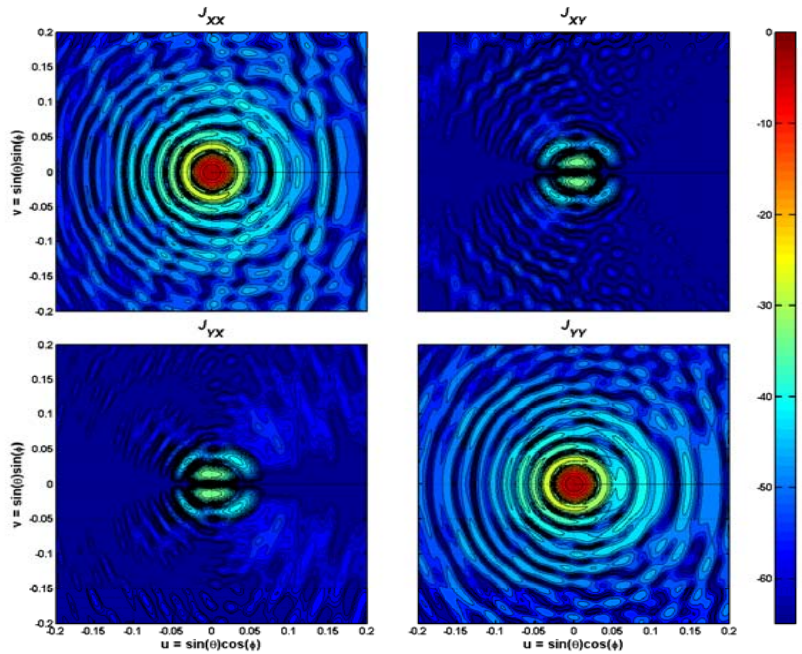
Sensitivity is king, but Dynamic Range or its proxies are the dominant queens

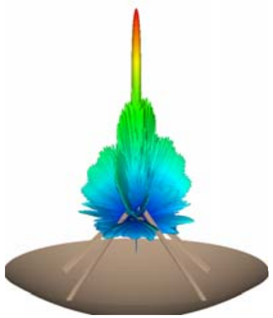
MeerKAT Dish Concept

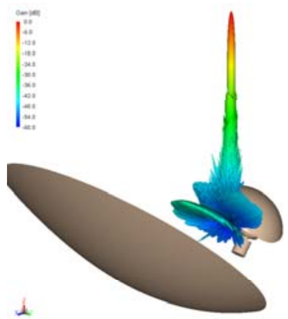


MeerKAT Dish Concept

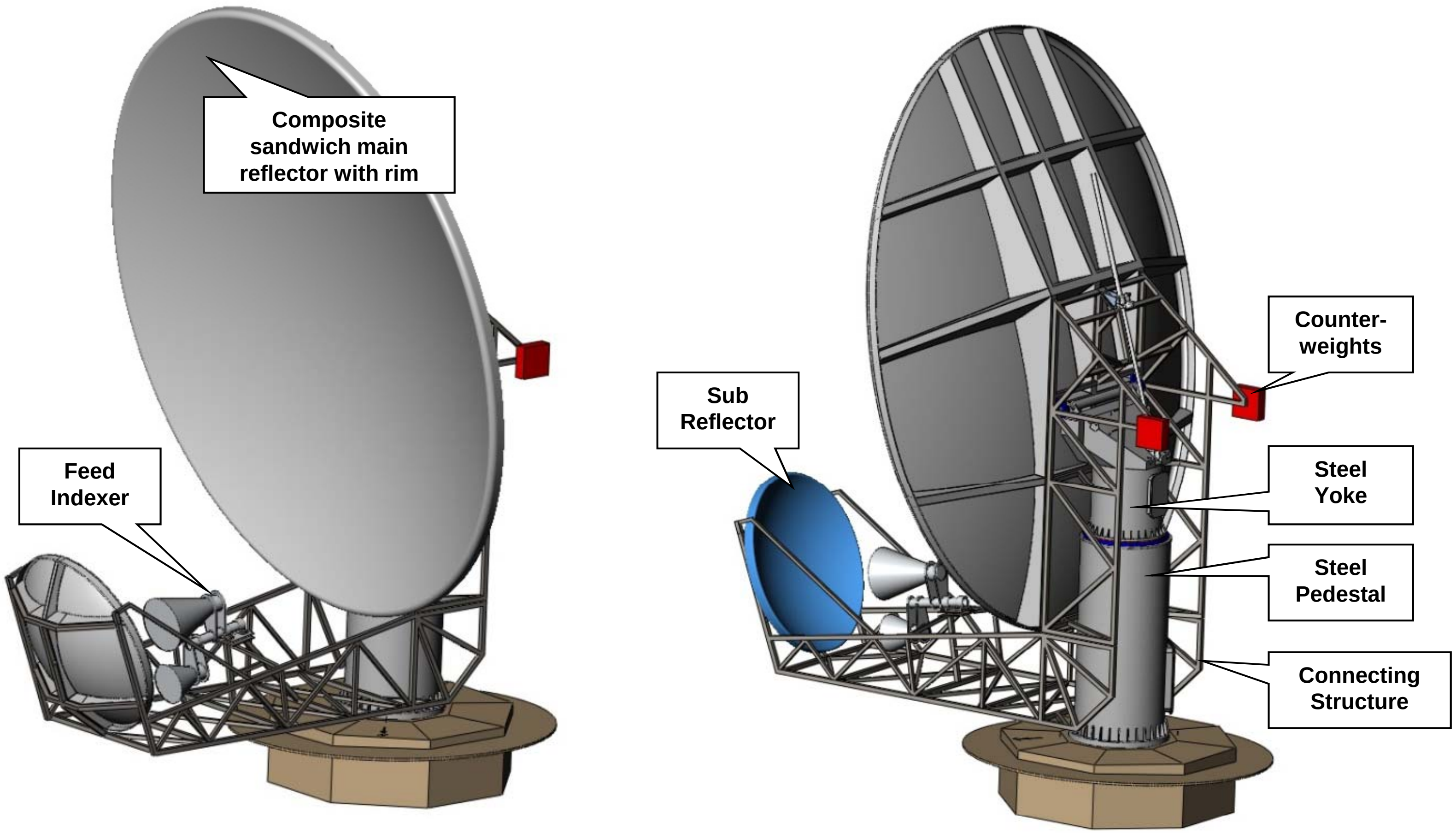








MeerKAT Dish Concept



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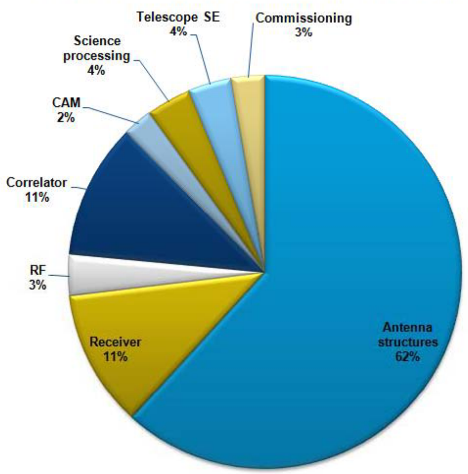
MeerKAT Cooling Trades

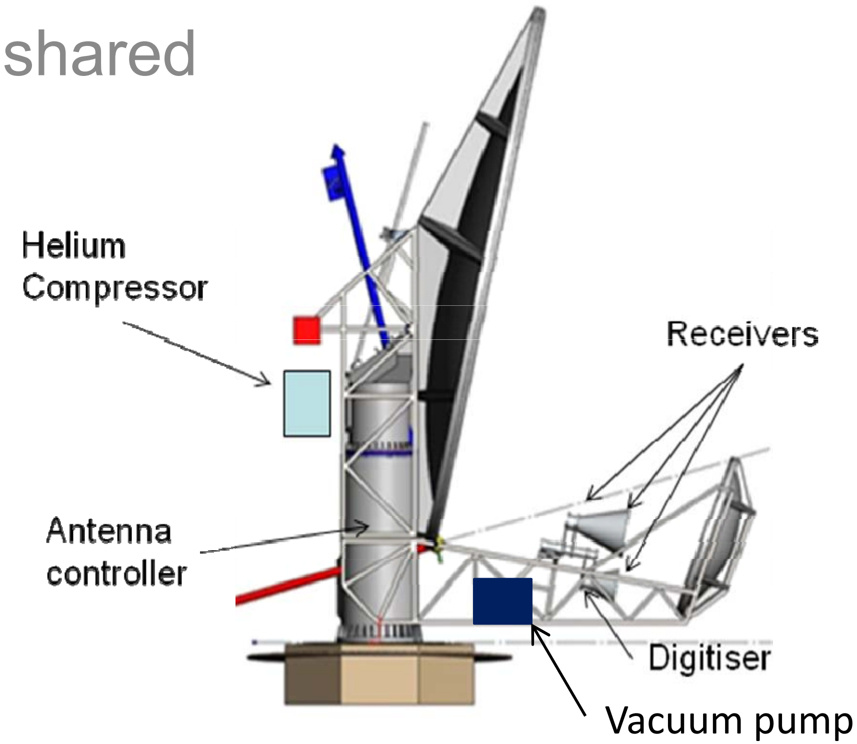
		GM	Stirling	Soft Vacuum
Performance				
	System sensitivity	$312m^2/K$	$248m^2/K$	$223m^2/K$
	% Improvement from Stirling	26%	0%	- 10%
	Physical LNA temperature	20K	75K	120K
Acquisition cost				
	Acquisition cost for L-band	+ R3.3M	-	- R3.7M
	Acquisition cost for UHF, L and X-band	- R10.1M	-	- R8.1M
	Maintenance infrastructure		Similar	
Operational Cost for 3 Receivers per receptor				
	Total cost per year	R6.7M	R7.7M	R6.5M
	Breakdown:			
	Normal power consumption (not pumping down for GM & Stirling)	7.3 kW	2.6 kW	2.9 kW
	Electricity cost	R1.7M	R0.6M	R0.7M
	Number of technicians	8	6	6
	Technicians cost	R4.0M	R3.0M	R3.0M
	Maintenance components	R0.9M	R4.0M	R2.8M
Mass				
	Mass reduction from baseline	- 19.2kg	-	- 18.9kg

MeerKAT Cooling Decision

- GM
- Single He-compressor (air-cooled), above azimuth rotator
- Single vacuum pump, on sub-reflector boom
- Compressor & vacuum pump shared amongst three receivers

➔ Maximum sensitivity





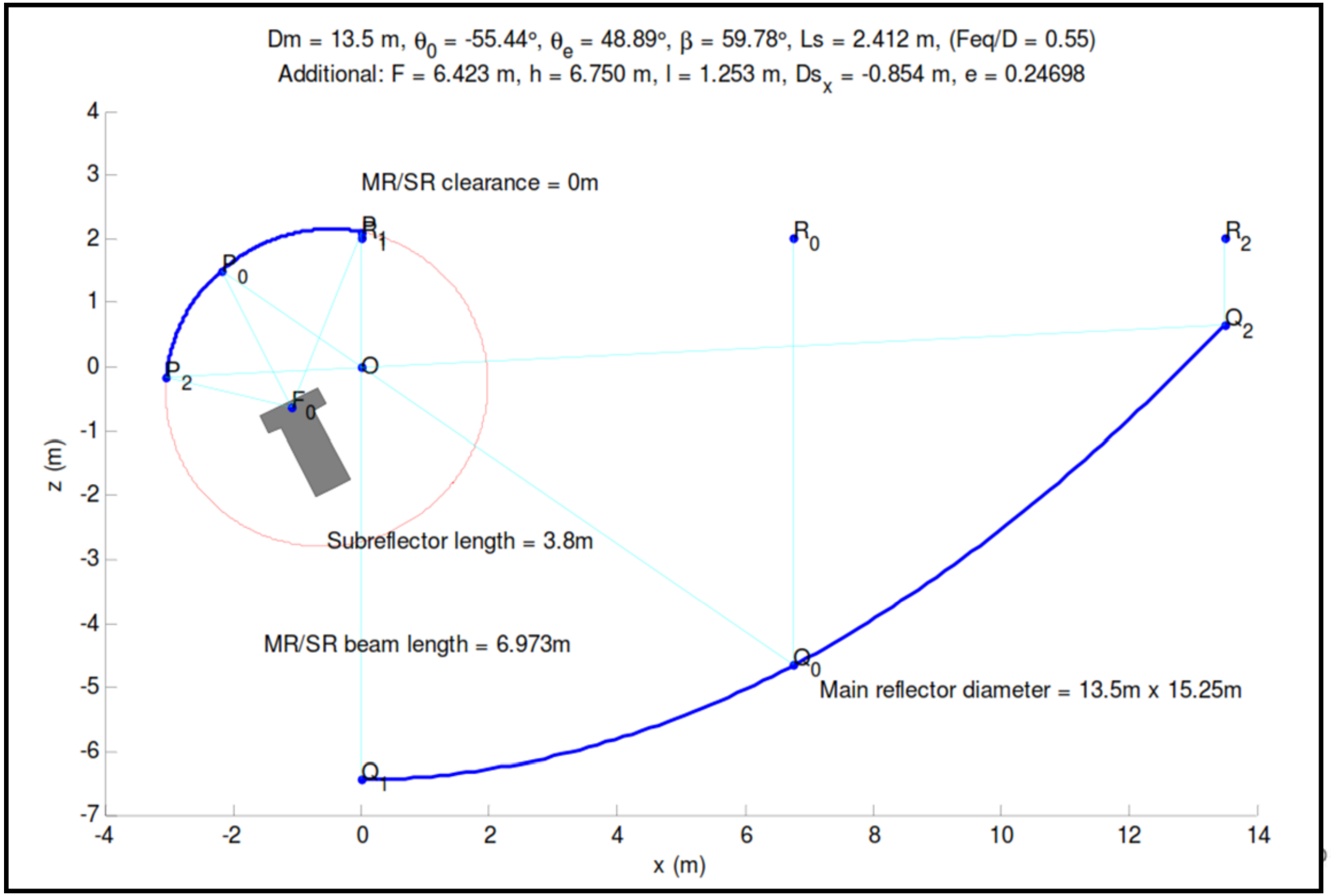
MeerKAT Availability

Likely driven by cryogenic receivers

Req #	***Requirement***
R.T.R01	The system shall have critical failures for less than 5% of annual operating time, where a critical failure is defined as a failure which results in the system not being available for science observations OR more than 10% of array elements not being available for science observations.
R.T.R02	The system shall have a mean time between critical failures of ≥684hrs.
R.T.R03	The system shall have a critical mean time to repair of ≤36hrs.

Offset Gregorian Optics

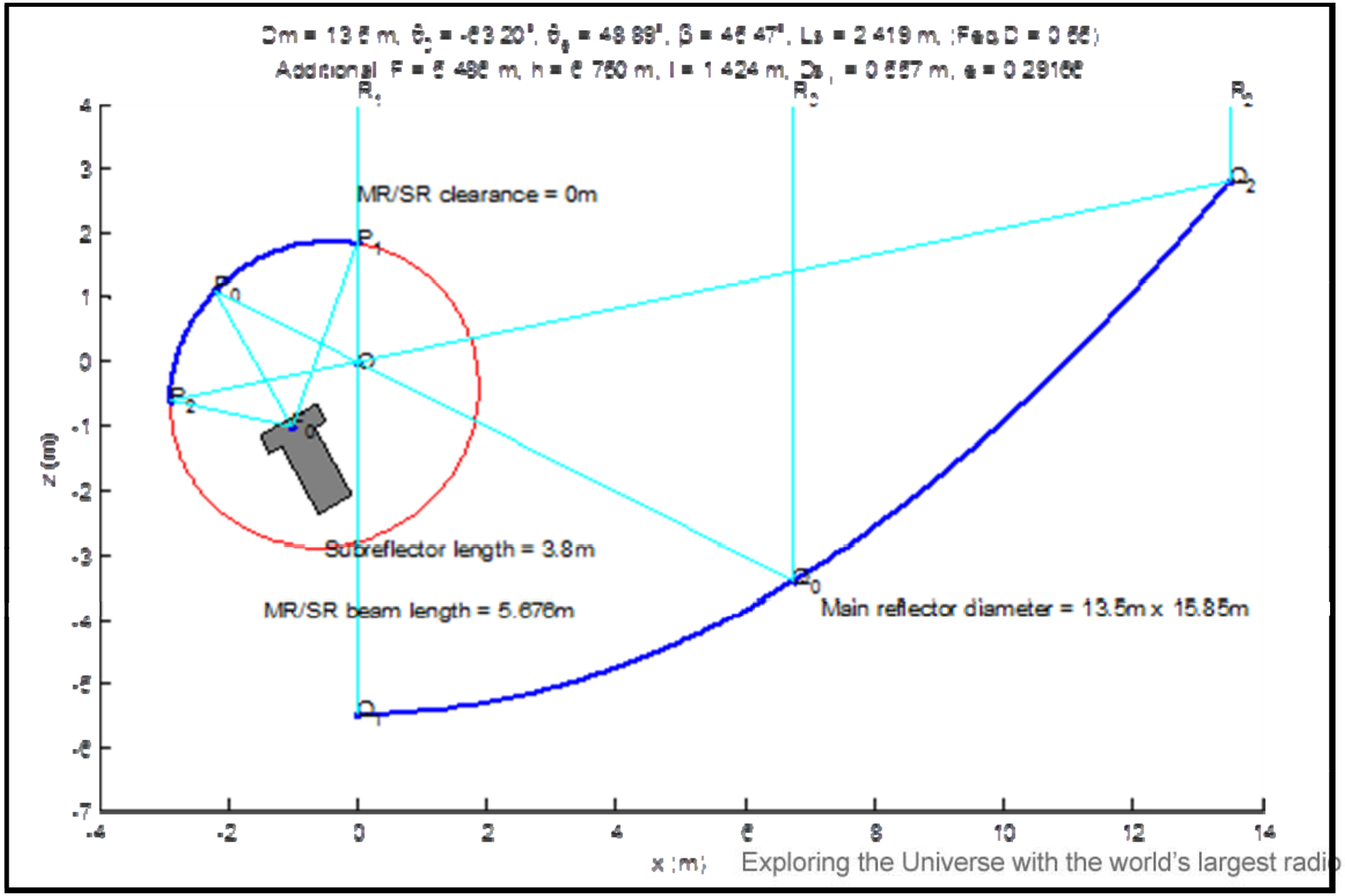
- Present EM best case (CEM)



telescope

Offset Gregorian Optics

- Present mechanical best case (FEA)



Offset Gregorian Optics

- FEA – CEM interactions tedious …

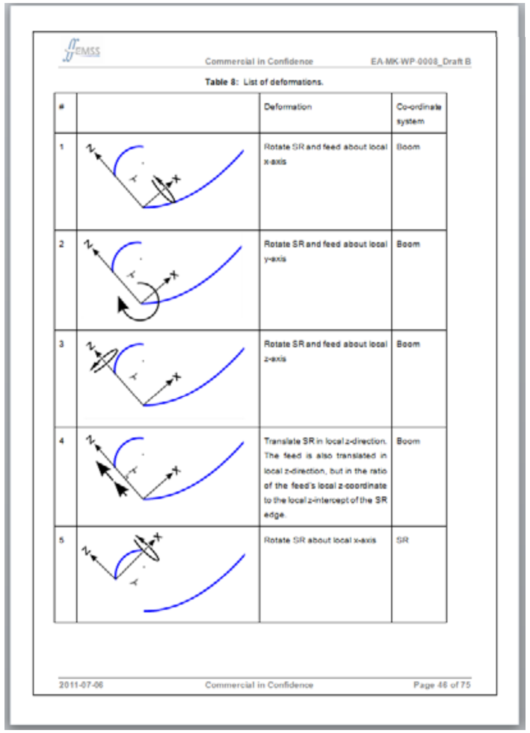

EMSS Commercial in Confidence EA-MK-WP-0008_Draft B

Table 8: List of deformations.

#		Deformation	Co-ordinate system
1		Rotate SR and feed about local x-axis	Boom
2		Rotate SR and feed about local y-axis	Boom
3		Rotate SR and feed about local z-axis	Boom
4		Translate SR in local z-direction. The feed is also translated in local z-direction, but in the ratio of the feed's local z-coordinate to the local z-intercept of the SR edge.	Boom
5		Rotate SR about local x-axis	SR

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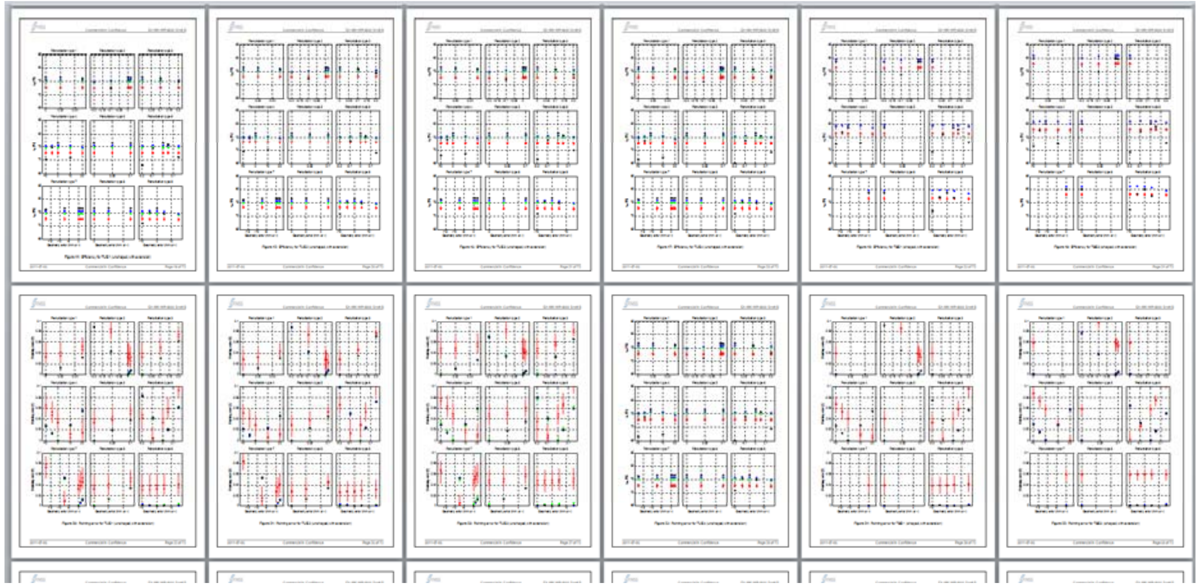
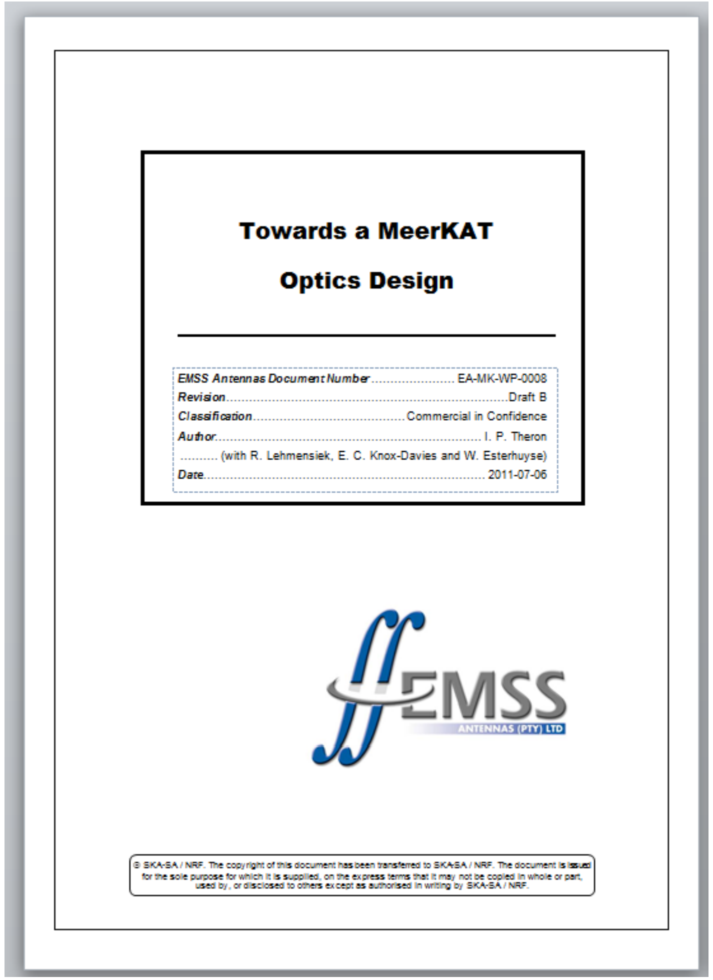


Offset Gregorian Optics

- Thinking documented
  [EA-MK-WP-0008]

- Draft A released in time for MeerKAT PDR next week

- Next step: Careful review, taking into account future-proofing



Towards a MeerKAT

Optics Design

EMSS Antennas Document Number	EA-MK-WP-0008
Revision	Draft B
Classification	Commercial in Confidence
Author	I. P. Theron
	(with R. Lehmensiek, E. C. Knox-Davies and W. Esterhuyse)
Date	2011-07-06

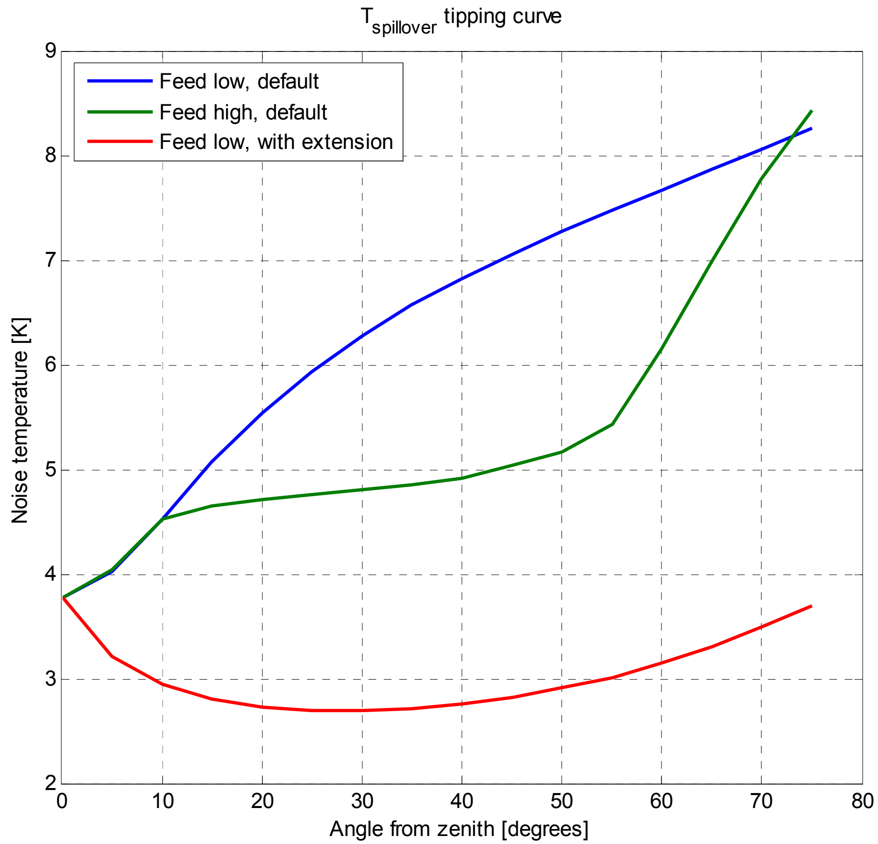
Optics History

		Optics	$D_{projected}$	$F_{main\ refl.}$	F/D	RMS
1	**XDM**	Prime-focus	15	7.5 m	0.50	2 mm
2	**KAT-7**	Prime-focus	12	4.56 m	0.38	1 mm
3	**MeerKAT**	Offset-Gregorian	13.5	TBD	TBD	≤ 1 mm

0.95/0.3mm

Tipping: Sub-reflector Down

- Sub-reflector extension (~ $2m^2$) ➔ $T_{spill,\ all\ angles} \leq 4K$ (L-band)
- Low enough in absolute terms, allows easy receiver access



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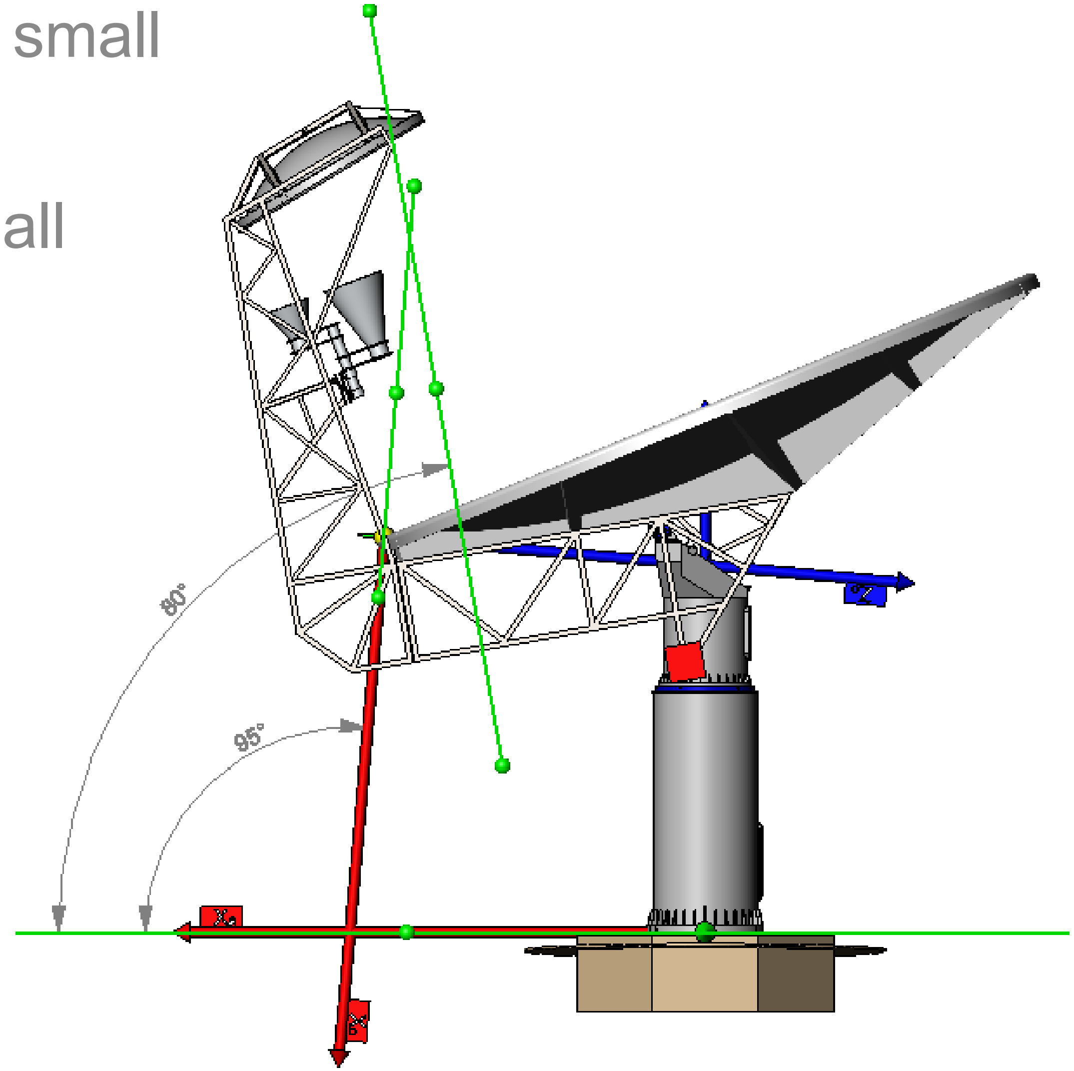
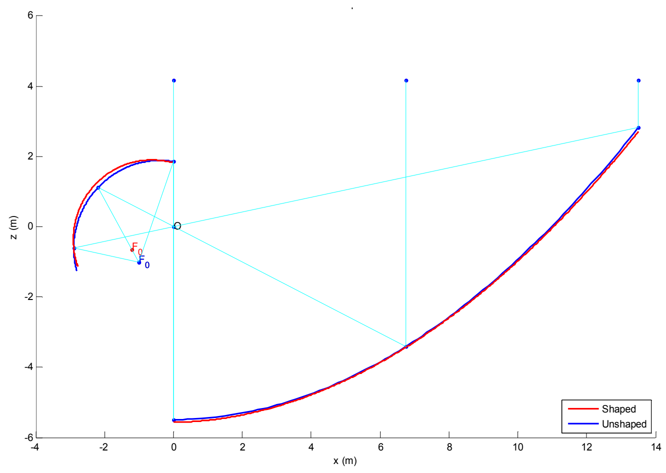
Stowing: Beam to Zenith

- Cost impact on structure small
- No water accumulation
- Impact on foundation small



Shaping the Reflectors

- Minor shaping of both reflectors being considered
- Decision TBD
- May add ~ 5% to A_e in L-band …
  - without degrading polarisation purity
  - without changing side-lobe (and spill-over) structure
  - without lifting side-lobe levels
  - *without excluding other feed art*



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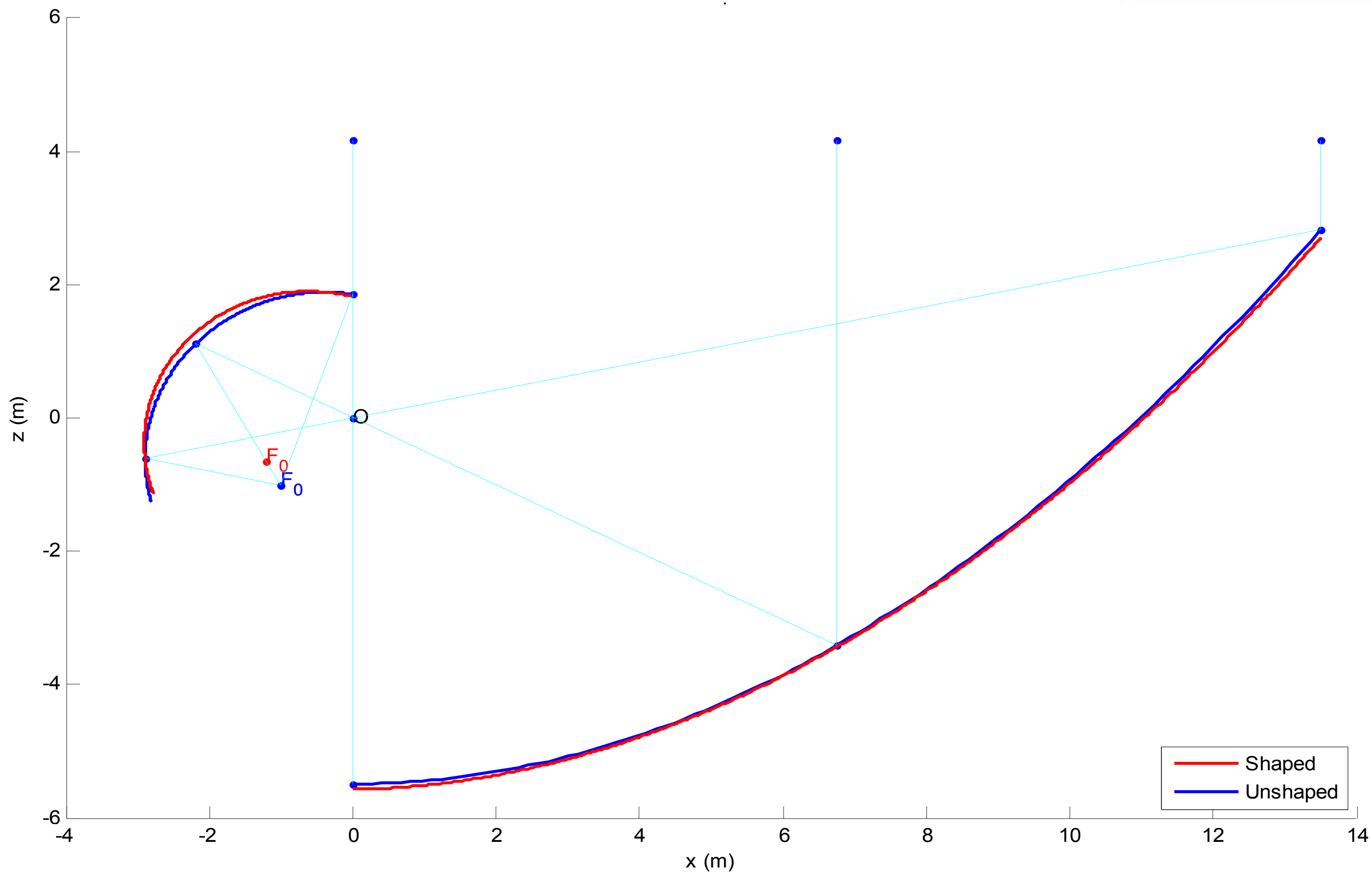
Shaping the Reflectors



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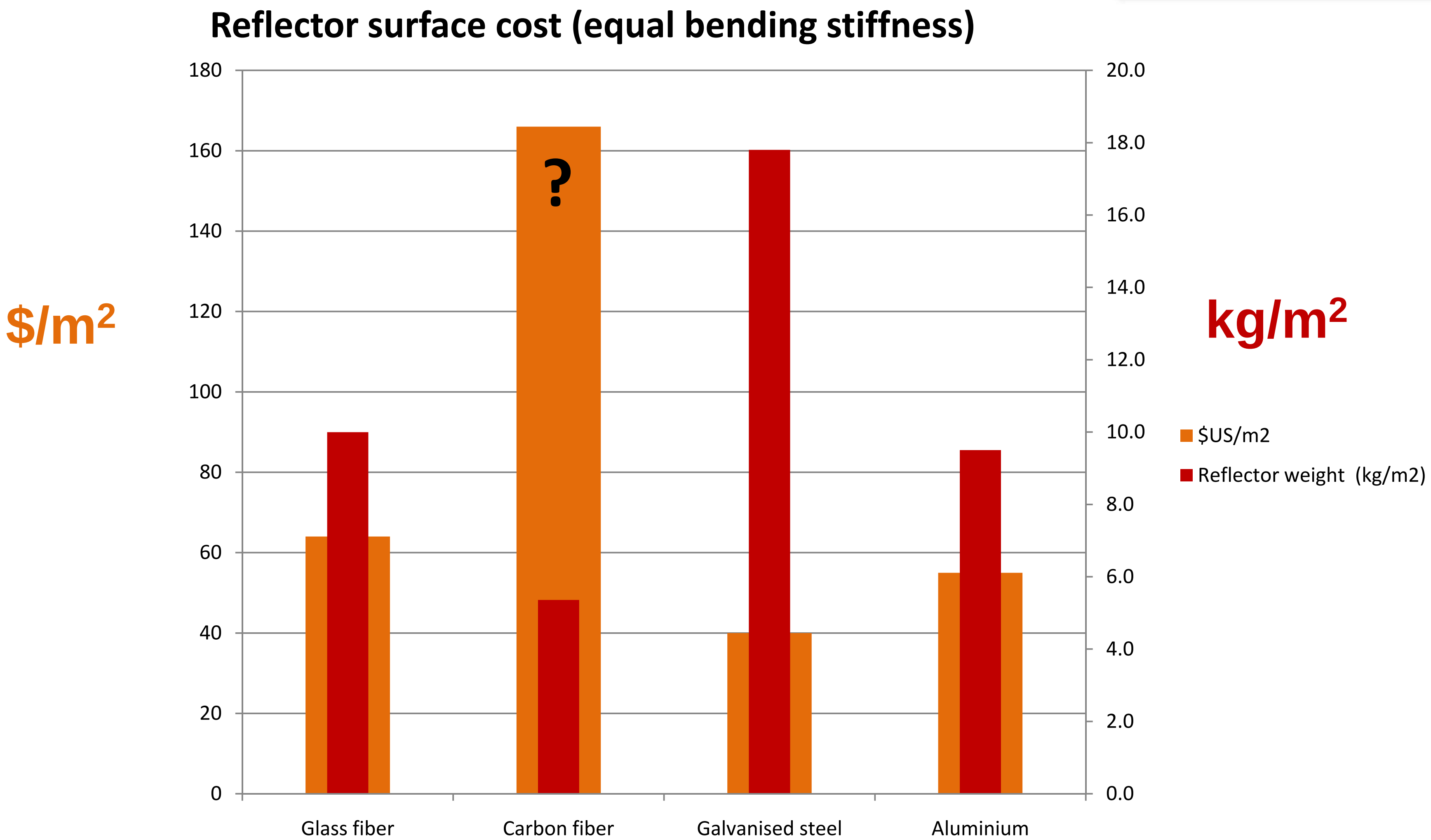
Material Options

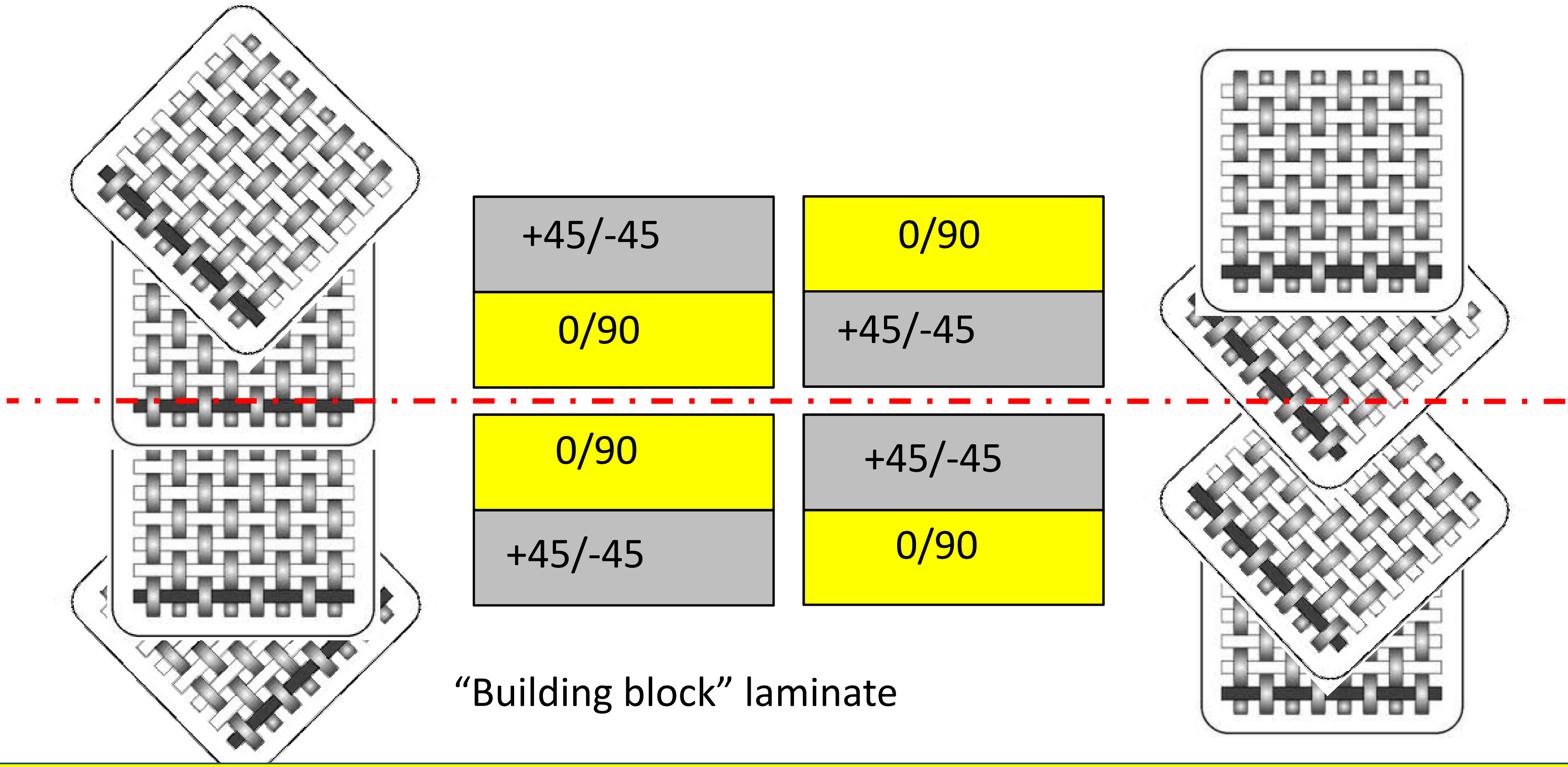


Material Options

- Glass fiber : attractive material
  - Single piece reflector (less time on site)
  - Simple process (high repeatability – KAT7)
  - Rapid manufacture (2/month – 1 mould)
  - Qualified mould = qualified reflector (once off adjustment, periodic confirmation)
  - Acceptable thermal match with steel
  - Cost effective
- However
  - Novel for this application (long term history?)
  - Some unanswered questions (e.g. long term environmental exposure)
  - Dedicated manufacturing facility

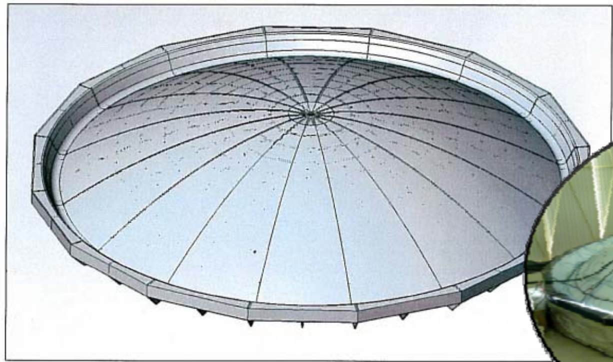
Composite Reflector Lay-up

- Need a Balanced and Symmetric lay-up to minimize distortions

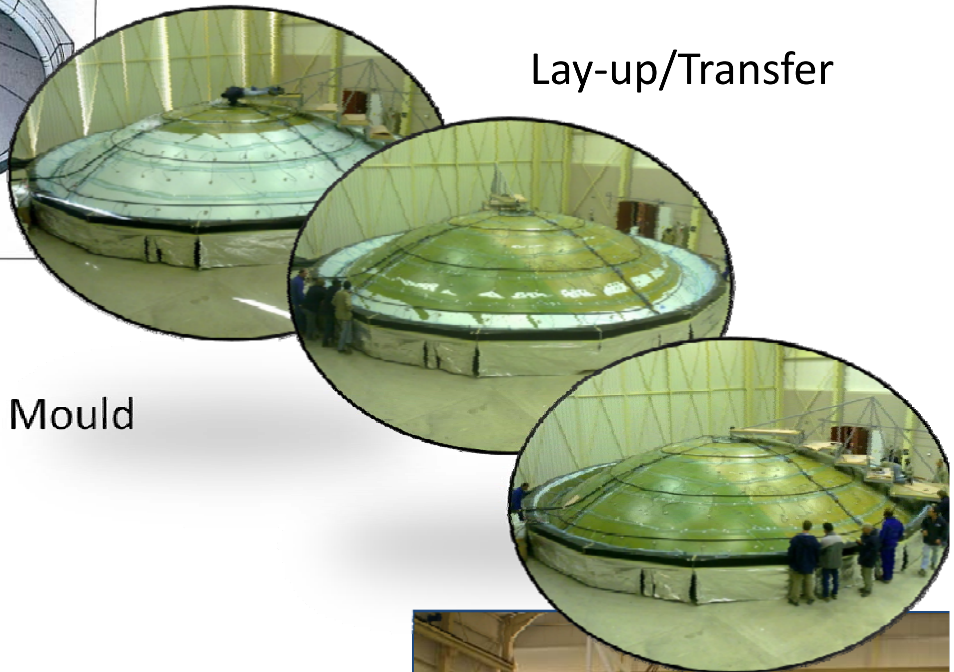


Balanced and symmetric. Minimum number of plies = 4, cannot make it any lighter

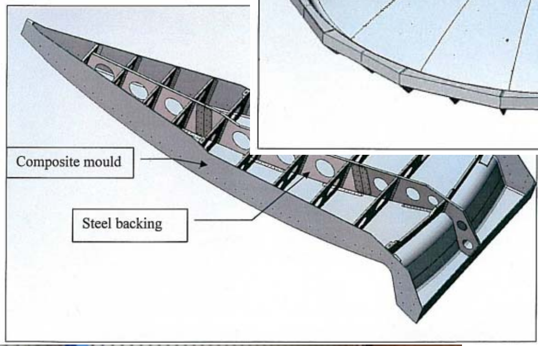
Reflector Manufacture (KAT7)



Mould Setup

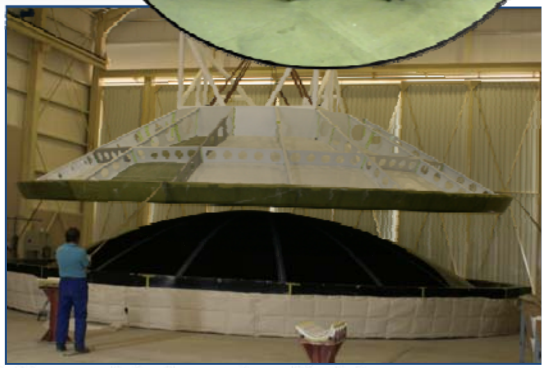


Lay-up/Transfer



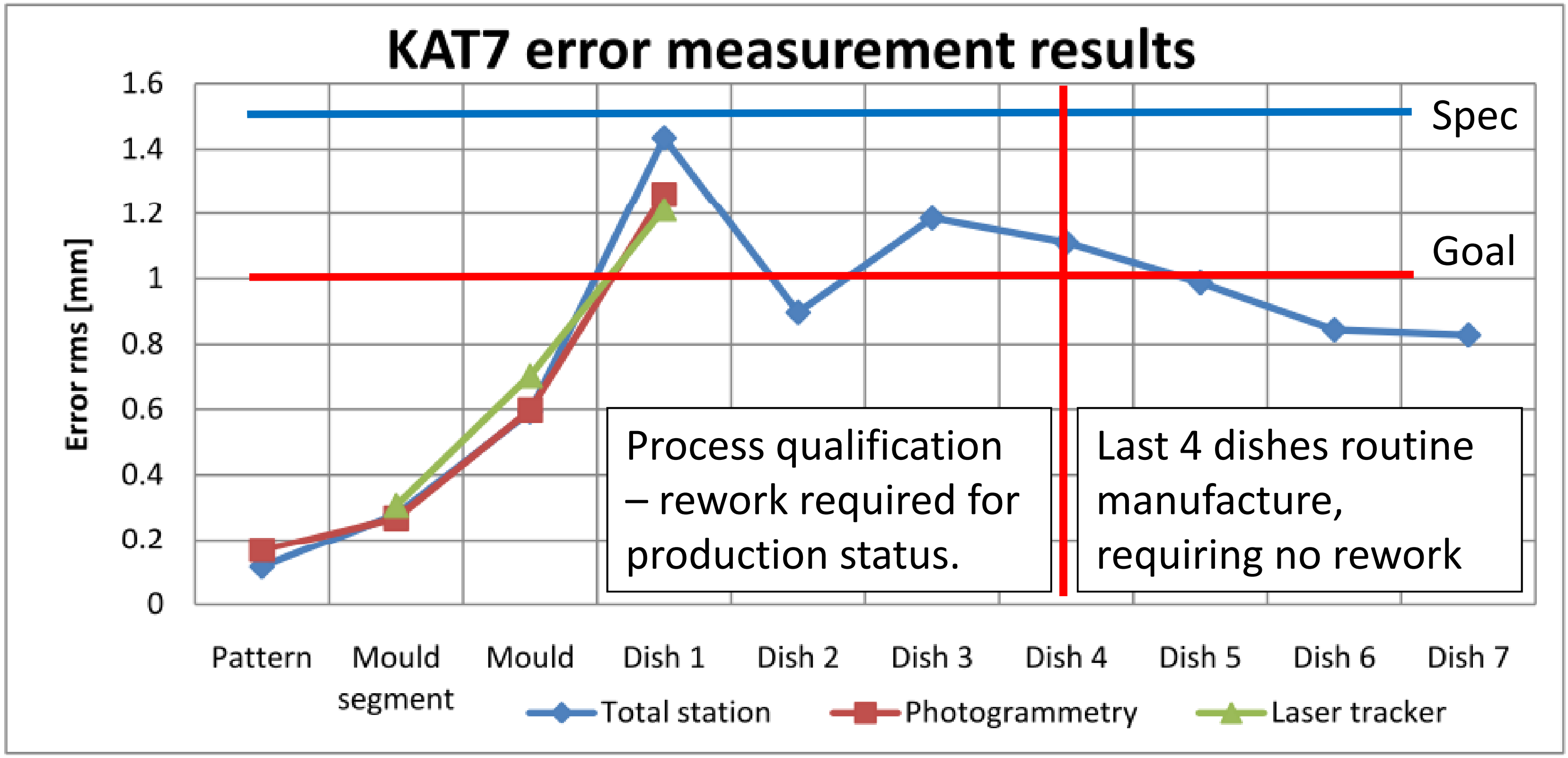
Glass-fibre Mould
Segments

Assemble Pattern



Machine Pattern

KAT7 Reflector Manufacturing Process Qualification



- More improvements pending for MeerKAT

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Mould Tolerance Build-up

Surface Accuracy

- Total surface error:
- Pattern error (E_{pat})
- Mould segment error (E_{ms})
- Mould assembly error (E_{ma})
- Process error (shrinkage) E_{proc}
- Load case error ($E_{LC(max)}$)

$$\text{Surface error} = (E^2_{pat} + E^2_{ms} + E^2_{ma}\ldots\ldots)^{0.5}$$

MeerKAT Mould Design

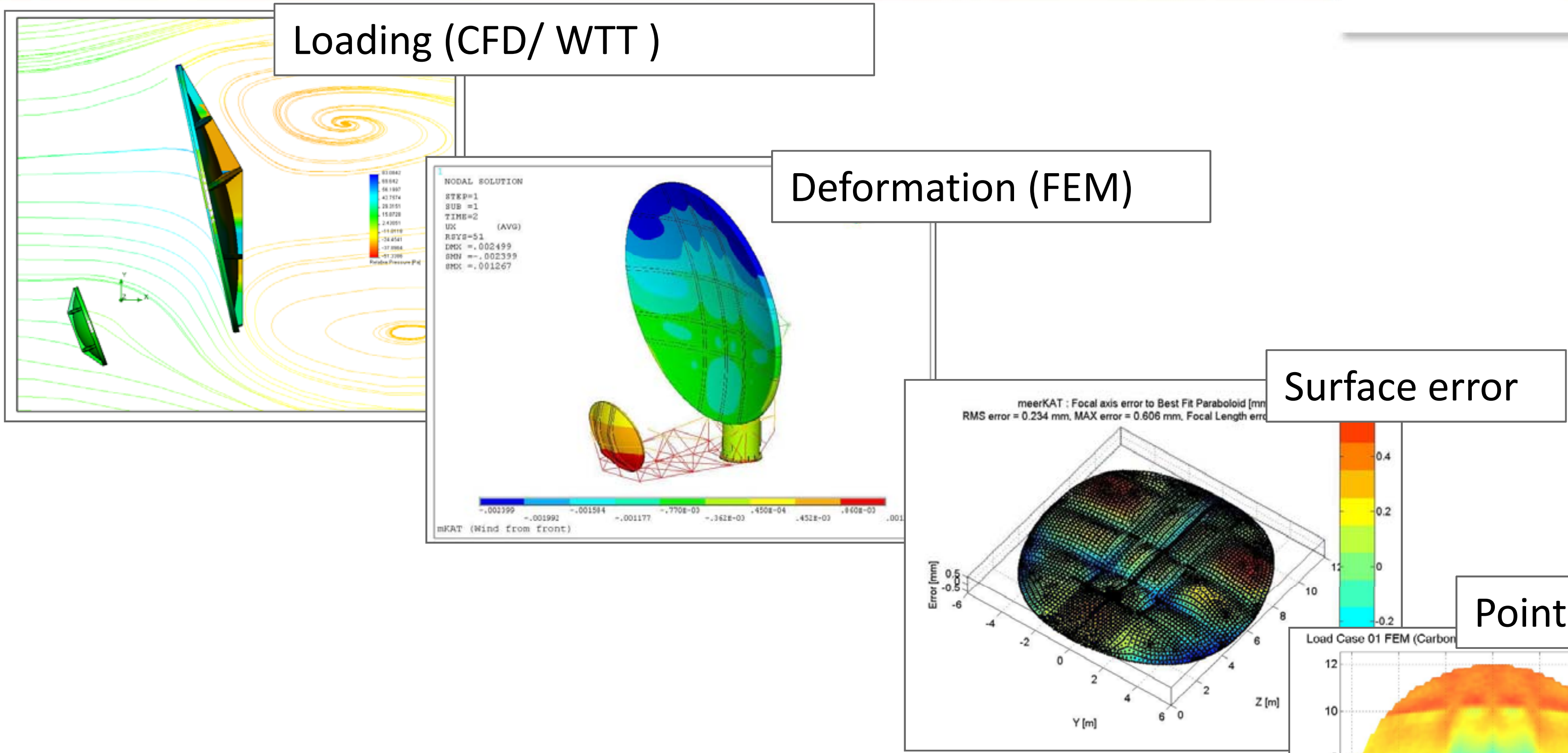
	Mould Option 1: Achieving 1mm RMS reflector surface accuracy	Mould Option 1: Achieving 0.9mm RMS reflector surface accuracy	Mould Option 2: Achieving 0.96mm RMS reflector surface accuracy	Mould Option 2: Achieving 0.86mm RMS reflector surface accuracy	Potential MeerKAT Improvement on surface accuracy
	Low cost pattern	High cost pattern	Low cost mould	High cost mould	
9. Operational dish surface error	0.99	0.90	0.96	0.86	0.63
8. Load conditions max error	0.3	0.3	0.3	0.3	0.30
7. Accuracy of unloaded dish	0.944	0.848	0.909	0.809	0.55
6. Mould to dish error	0.6	0.6	0.6	0.6	0.40? – curing distortion study
5. Accuracy of mould	0.728	0.600	0.682	0.543	0.38
4. Mould assembly error	0.523	0.523	0.523	0.523	0.35? – mould design study
3. Accuracy of mould segments	0.507	0.294	0.438	0.146	0.15
2. Pattern to mould segments error	0.255	0.255			
1. Accuracy of pattern	0.438	0.146			
(orange)	standard errors for all options assumption				
(yellow)	"low" quality initial machined product				
(green)	"high" quality initial machined product				

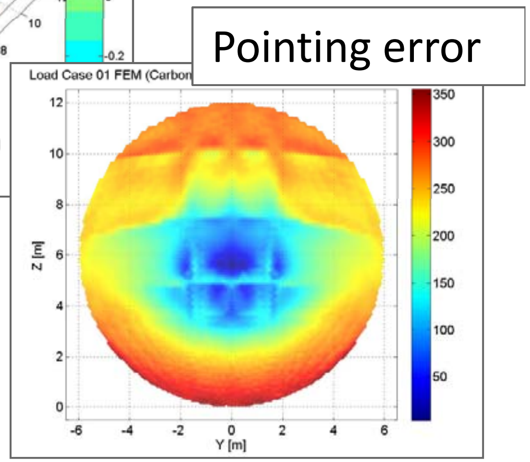
- Eliminate 1 and 2
- Current solution good enough for MeerKAT
- Study to improve major error contributors (4 and 6) underway

Reflecting Surface: Mesh

- MeerKAT mesh to be similar to KAT-7 (Al, Φ250μm, 30/", 100mm overlap)
- Excellent predicted & measured reflection from UHF to X-band
  - Skin-depth problem << 450MHz
  - Transmission problem > 14.5GHz (1.2K vs. $0.3K_{Aluminium}$ at 14.5GHz)

MeerKAT Studies - Wind





Full EM model using deflected FEM geometry

Validation ⟷

Dish Manufacture (KAT7)

Material Qualification

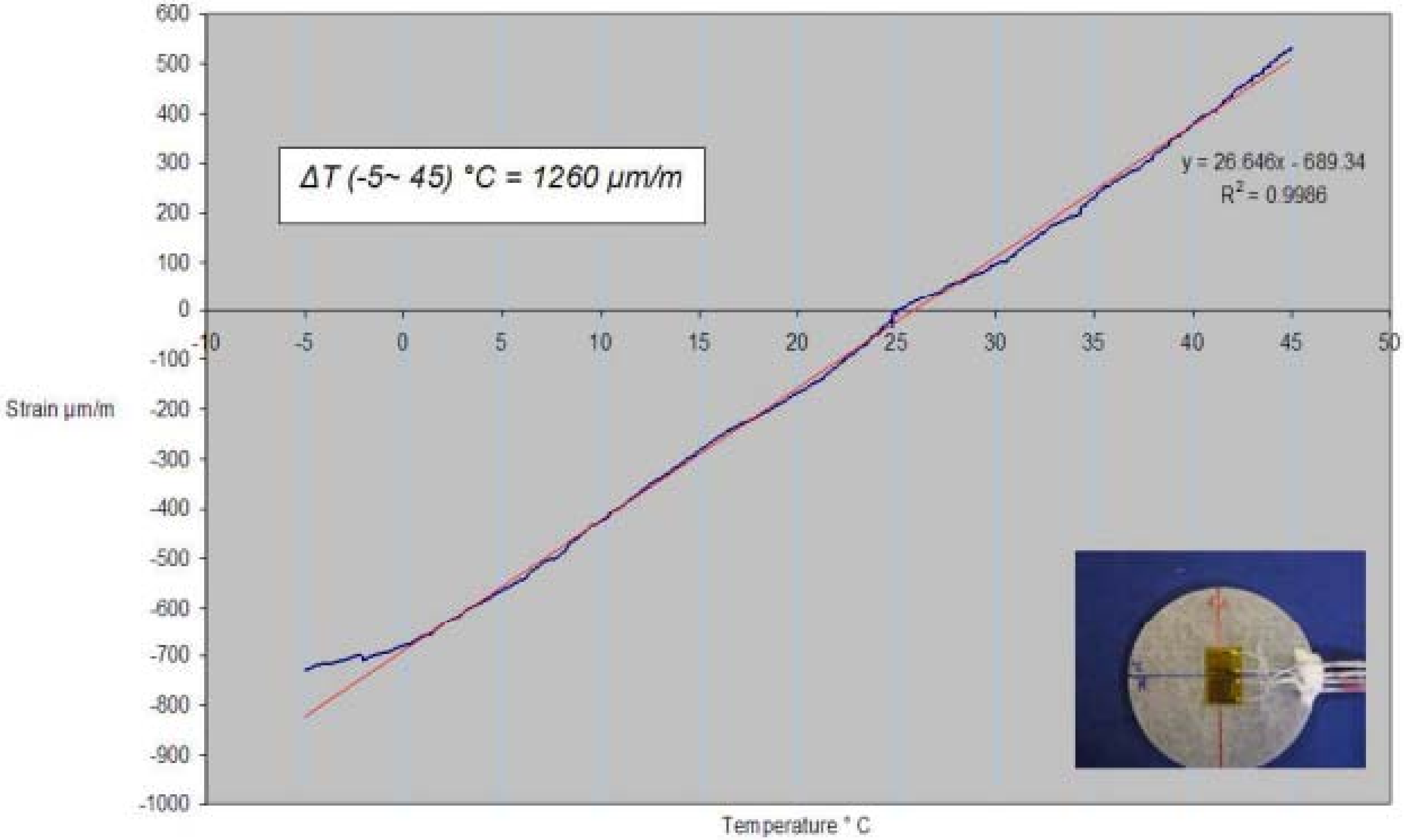
- Material qualification
  - Structural (reflective surface)
  - Environmental (UV/corrosion/fungus)
  - Radio quality evaluation to quantify effects of environment

- Structural tests almost completed
  - Strength, stiffness, shear properties
  - Fatigue
  - Creep

- **Test program scheduled for completion Oct 2011**

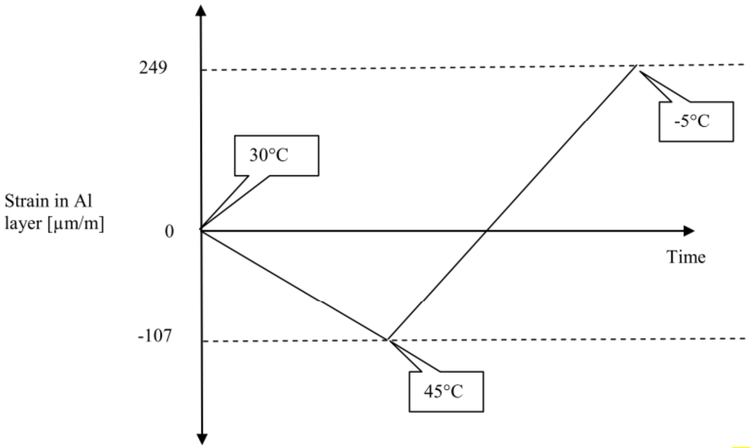
Material Qualification

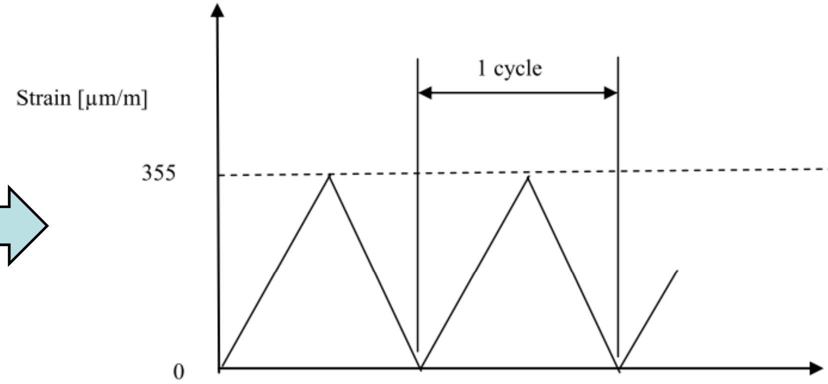
- Thermal Fatigue

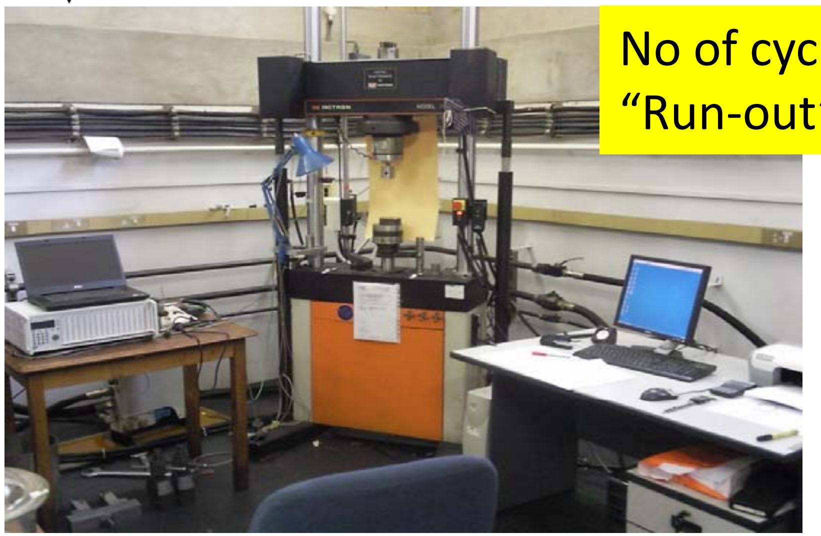


Material Qualification

- Thermal Mechanical Fatigue Test





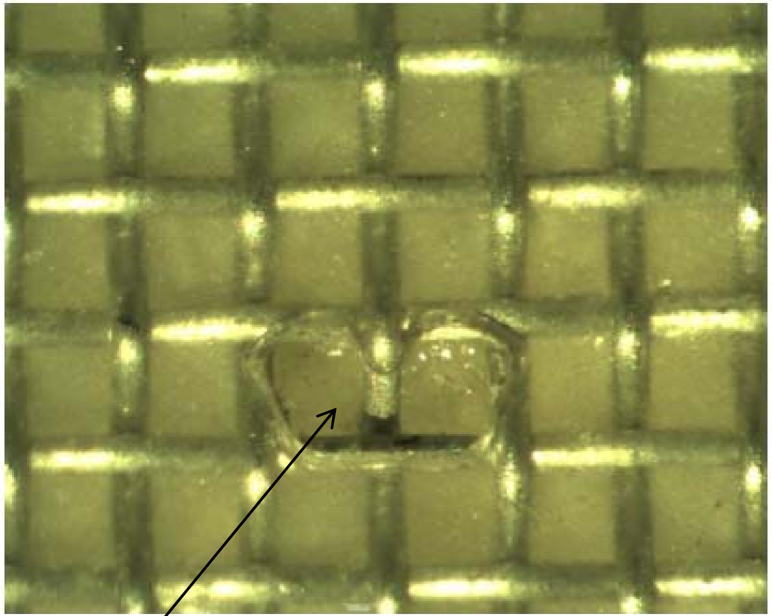


No of cycles = 365x30x5,
“Run-out” 1e6 cycles

Material Qualification

- Thermal Mechanical Fatigue Test

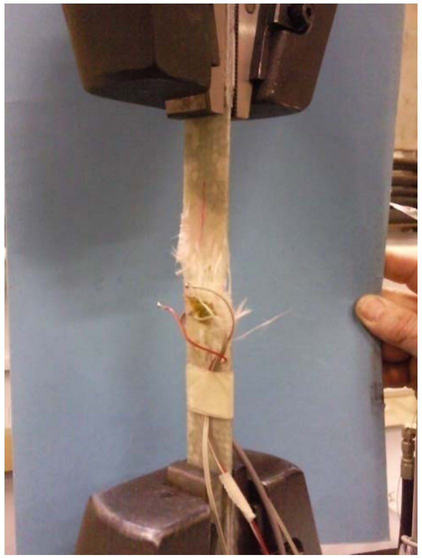
Specimen Number	Batch Number	Stress Range [MPa]	Number of cycles completed	Inspections
2304	1	6.76	55000	No evidence
2305	1	6.67	55000	of fatigue
2306	1	6.52	55000	damage to
2307	1	6.63	55000	the wire
2308	1	6.60	55000	mesh on any
2309	1	6.61	55000	of the ten
2310	1	6.64	55000	specimens
2311	1	6.63	55000	tested,
2312	1	6.62	55000	including the
2313	1	6.68	55000	run-out test
2313	1	6.68	1000000	

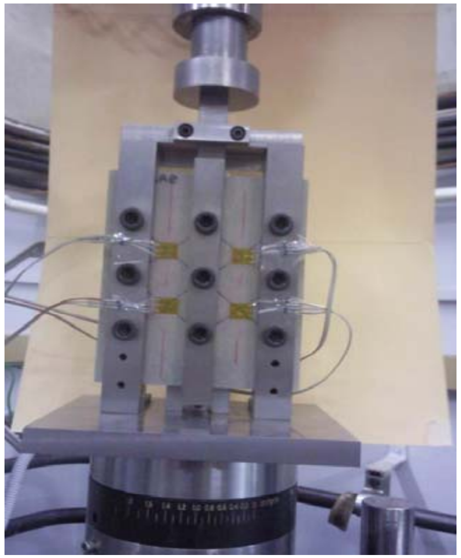


Manufacturing void (microscopic) – no evidence of deterioration in thermal fatigue run-out test

Material Qualification

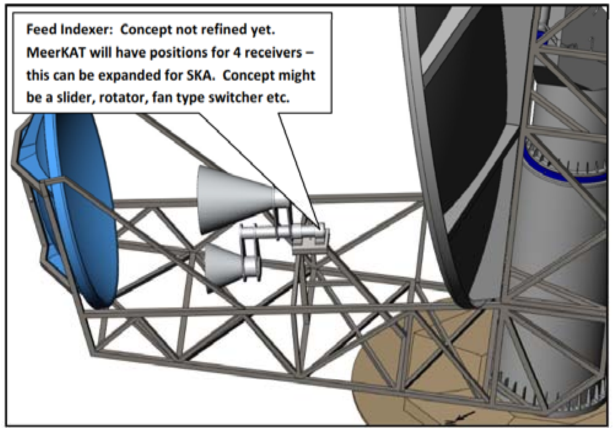
- Mechanical properties (ASTM/ISO)
  - Tension
  - Compression
  - Shear
  - Creep

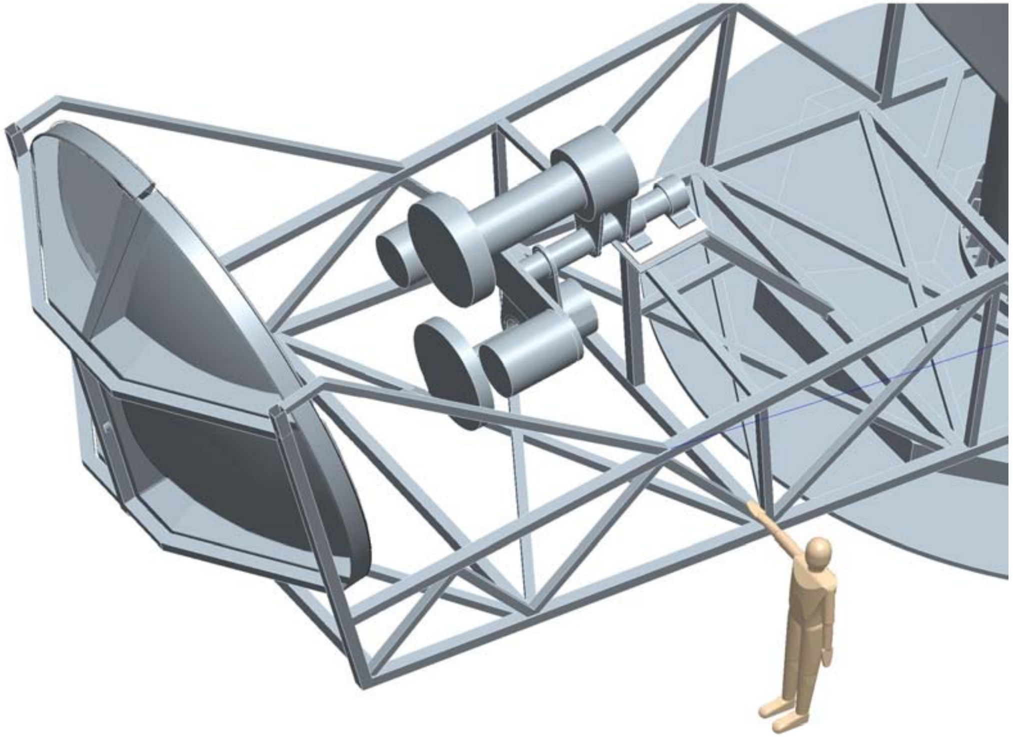





Multiple Receivers

- Indexer (probably a slider)
- All operational, all the time





Receiver Envelopes

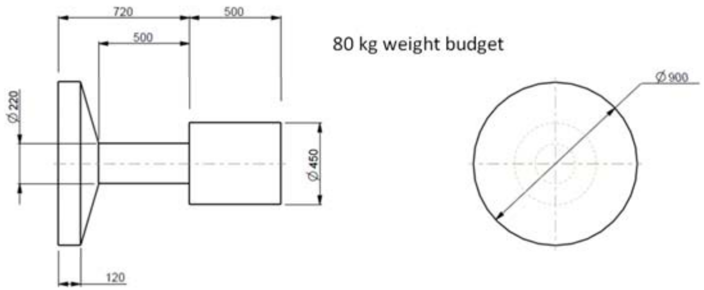


Figure 39 L-band (1 – 1.75GHz) Receiver envelope

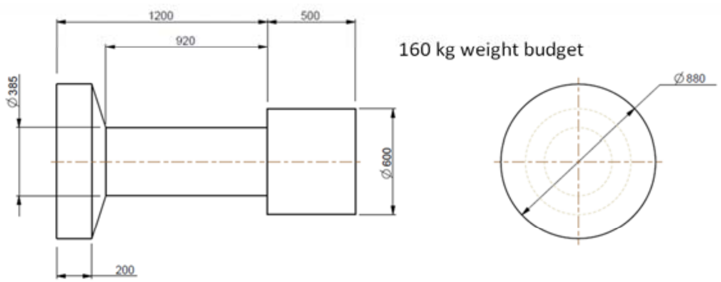


Figure 40 UHF-band (0.58 – 1.015GHz) Receiver envelope

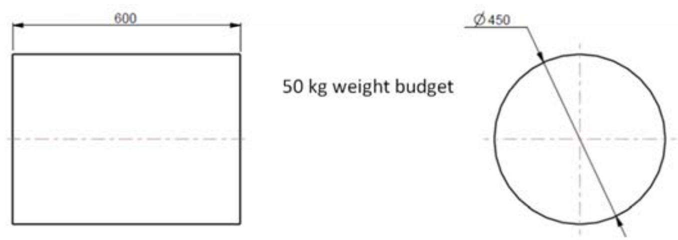
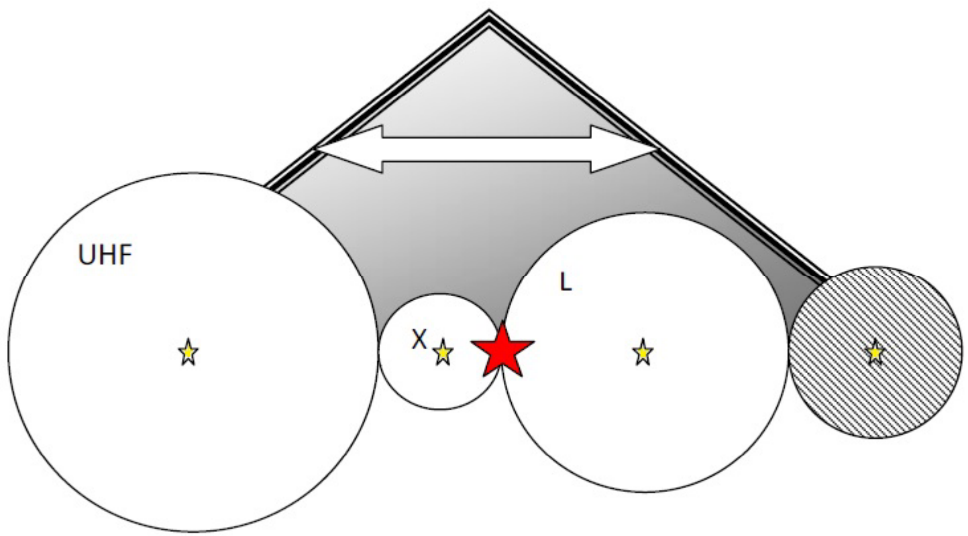
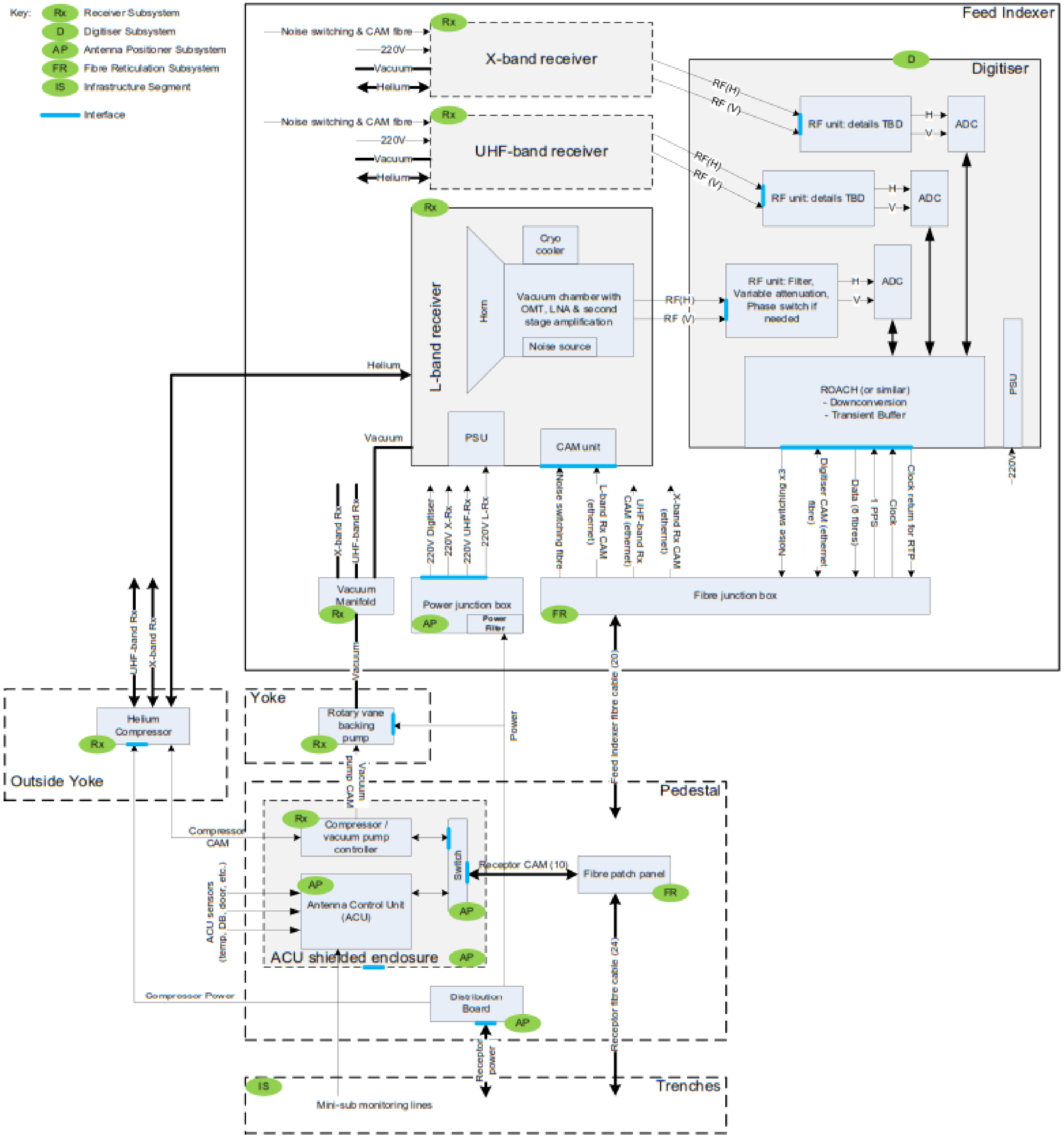


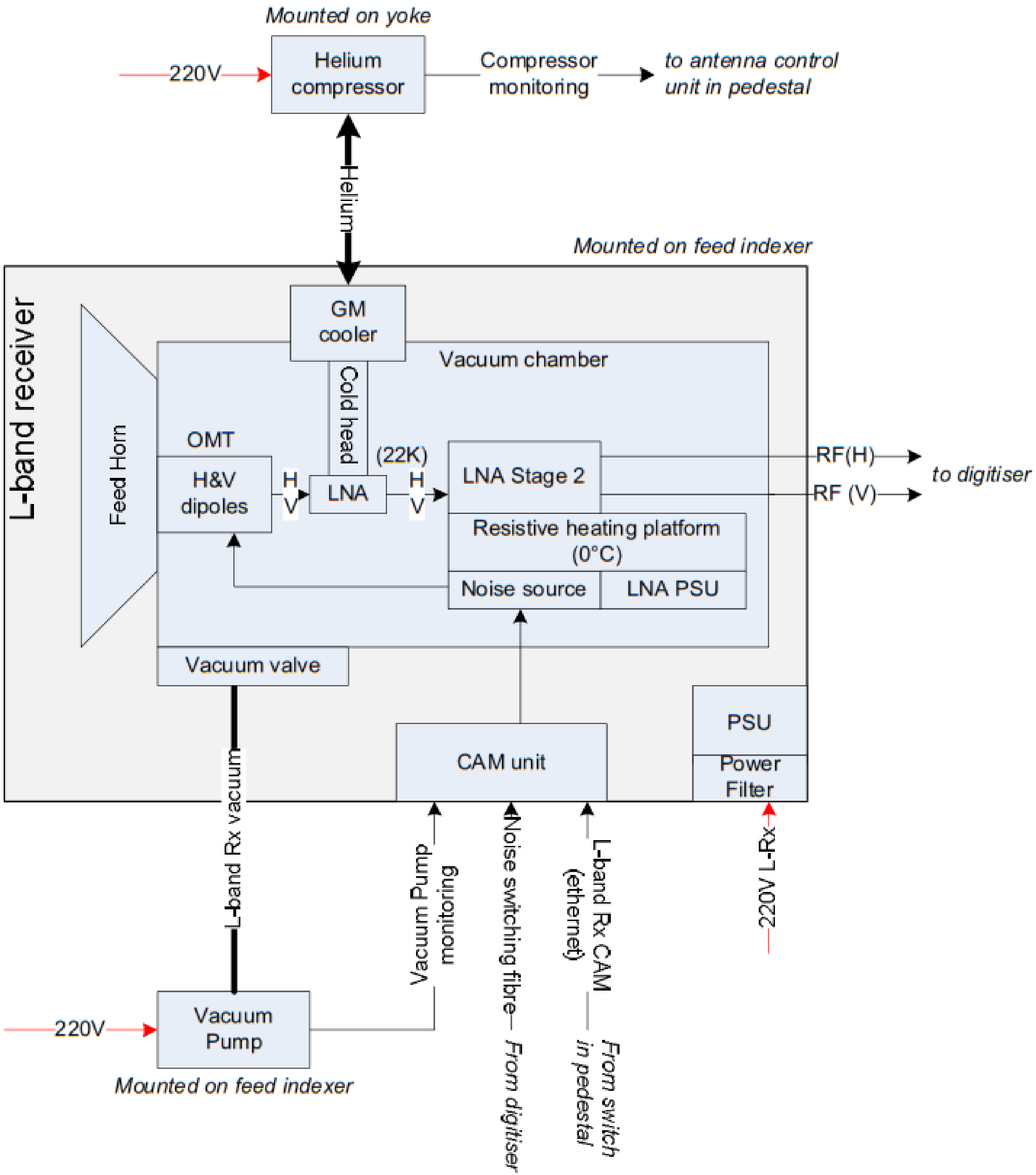
Figure 41 X-band (8 – 14.5GHz) Receiver envelope

- 4'th position possible
- Future FPA at either focal position



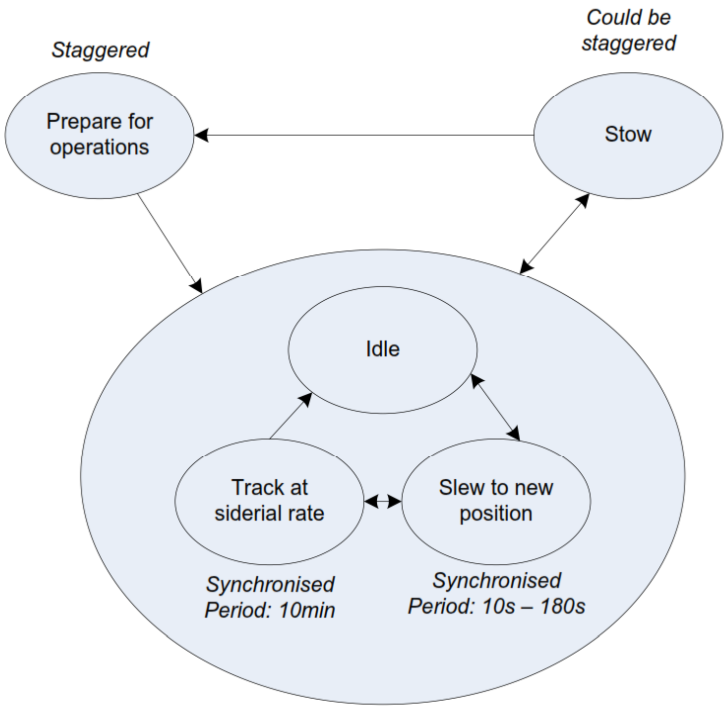
Interconnections


Key:
Rx Receiver Subsystem
D Digitiser Subsystem
AP Antenna Positioner Subsystem
FR Fibre Reticulation Subsystem
IS Infrastructure Segment
Interface
Feed Indexer
X-band receiver
UHF-band receiver
L-band receiver
Noise switching & CAM fibre
220V
Vacuum
Helium
Digitiser
RF(H)
RF (V)
RF unit: details TBD
ADC
Cryo cooler
Horn
Vacuum chamber with OMT, LNA & second stage amplification
Noise source
RF unit: Filter, Variable attenuation, Phase switch if needed
ROACH (or similar) - Downconversion - Transient Buffer
PSU
CAM unit
Vacuum Manifold
Power junction box
Power Filter
Fibre junction box
220V Digitiser
220V X-Rx
220V UHF-Rx
220V L-Rx
Noise switching fibre
L-band Rx CAM (ethernet)
UHF-band Rx CAM (ethernet)
X-band Rx CAM (ethernet)
Noise switching x3
Digitiser CAM (ethernet fibre)
Data (6 fibres)
1 PPS
Clock
Clock return for RTP
X-band Rx
UHF-band Rx
Helium Compressor
Outside Yoke
Yoke
Rotary vane backing pump
Power
Feed Indexer fibre cable (20)
Pedestal
Compressor / vacuum pump controller
Compressor CAM
Switch
Receptor CAM (10)
Fibre patch panel
Antenna Control Unit (ACU)
ACU sensors (temp, DB, door, etc.)
ACU shielded enclosure
Compressor Power
Distribution Board
Receptor power
Receptor fibre cable (24)
Trenches
Mini-sub monitoring lines


Mounted on yoke
220V
Helium compressor
Compressor monitoring
to antenna control unit in pedestal
Helium
Mounted on feed indexer
L-band receiver
GM cooler
Vacuum chamber
Cold head
Feed Horn
OMT
H&V dipoles
H
V
LNA
(22K)
LNA Stage 2
RF(H)
RF (V)
to digitiser
Resistive heating platform (0°C)
Noise source
LNA PSU
Vacuum valve
PSU
Power Filter
CAM unit
L-band Rx vacuum
Vacuum Pump monitoring
Noise switching fibre— From digitiser
L-band Rx CAM (ethernet) — From switch in pedestal
220V L-Rx
220V
Vacuum Pump
Mounted on feed indexer

Power Reticulation

- 23kVA maximum per receptor (2/3 for receivers)



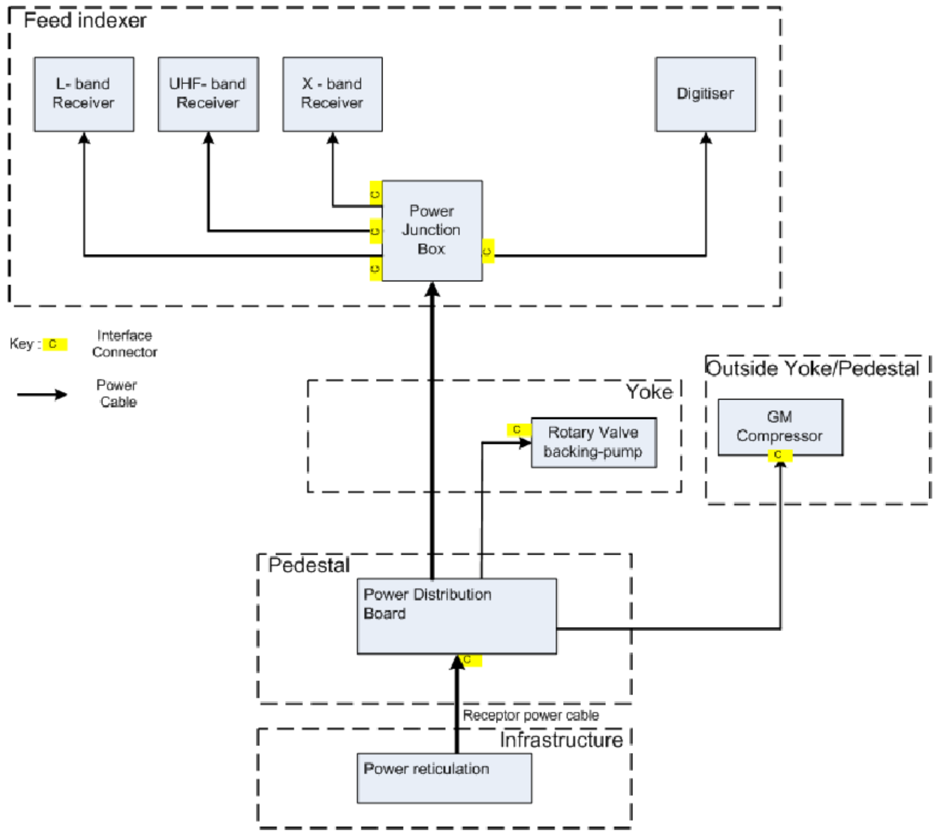
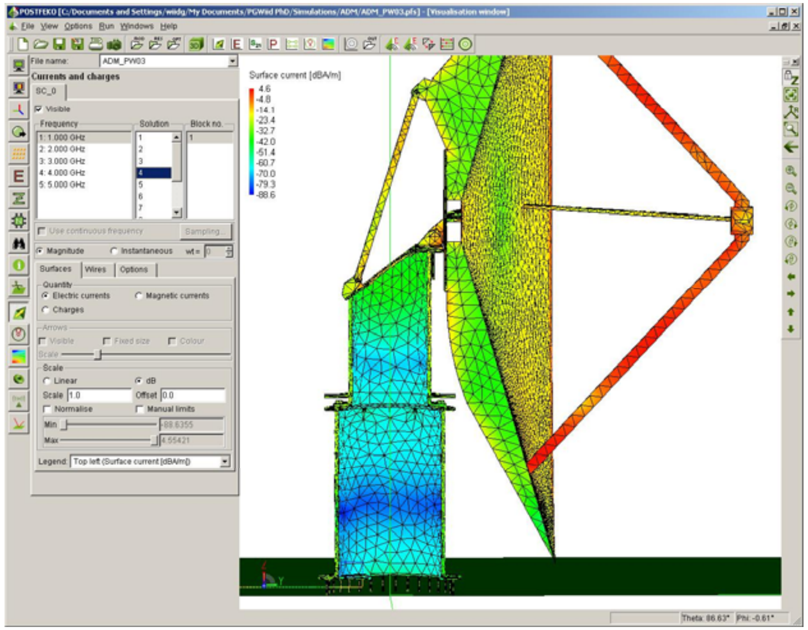


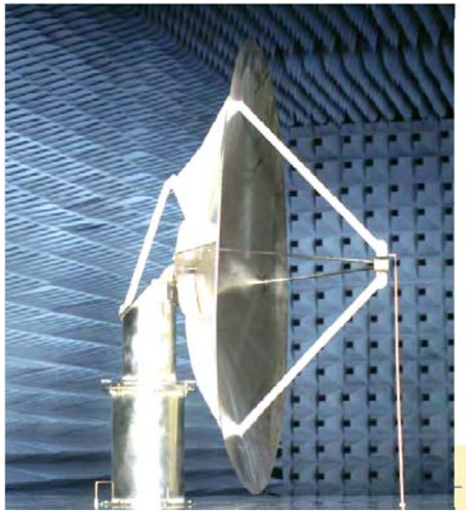
Figure 3: Receptor Power interfaces

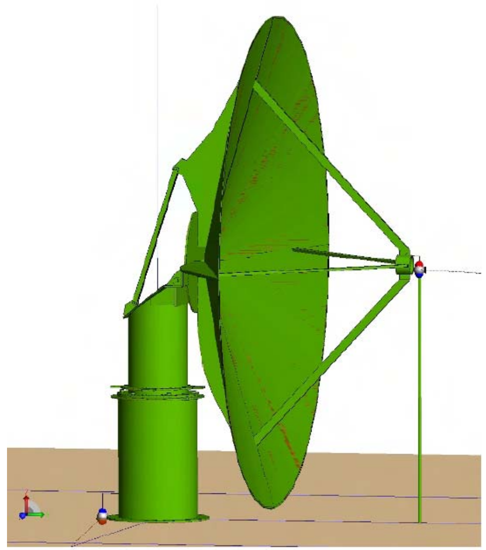
Lightning Protection

SKA SQUARE KILOMETRE ARRAY

- Good physical understanding of current flow
- Agreement between (scale) modeling and measurements
- KAT-7 learning will transfer to MeerKAT

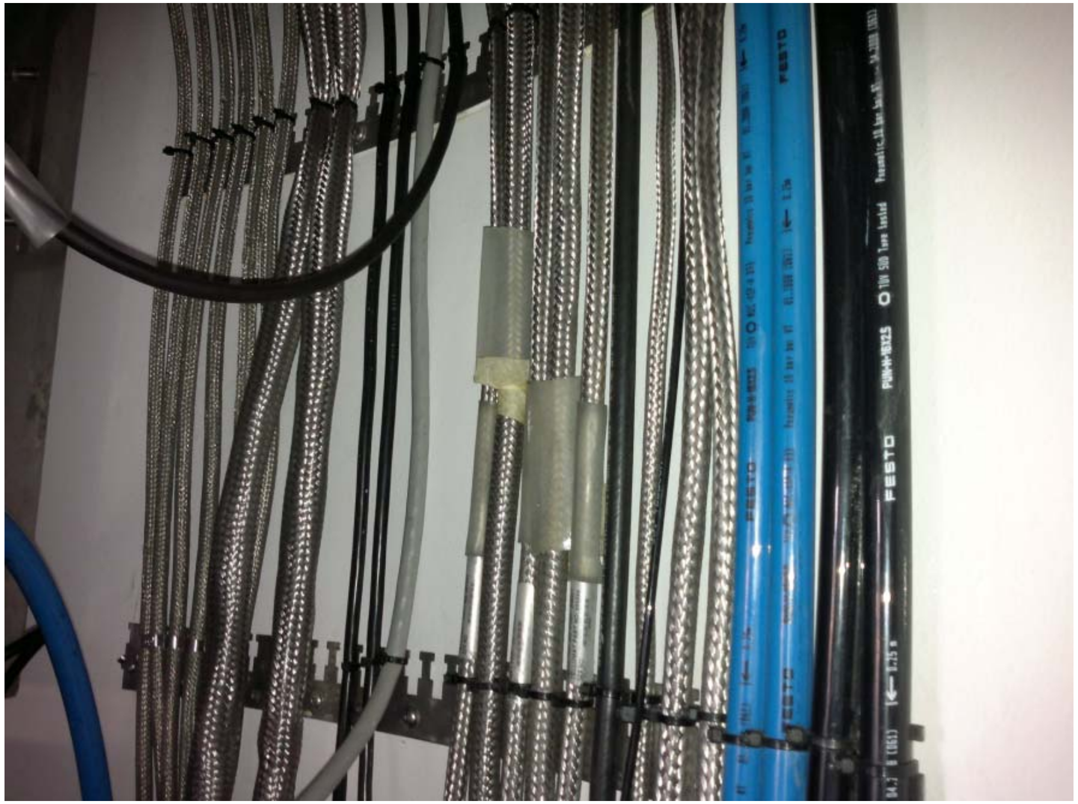




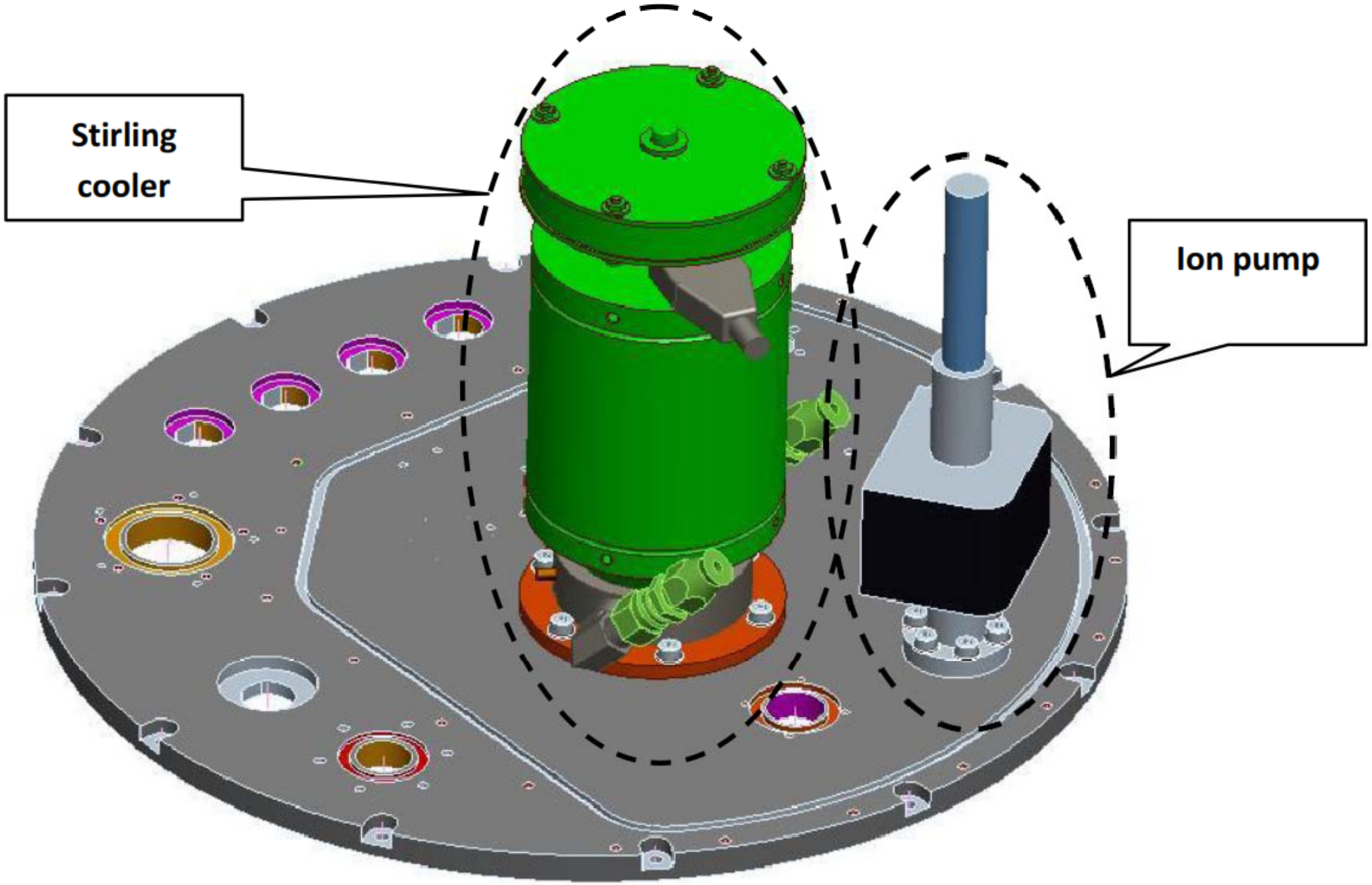


EMC/EMI Philosophy

- Minimise current loops
- Plan for easy improvements



KAT-7 Cryogenic Solution



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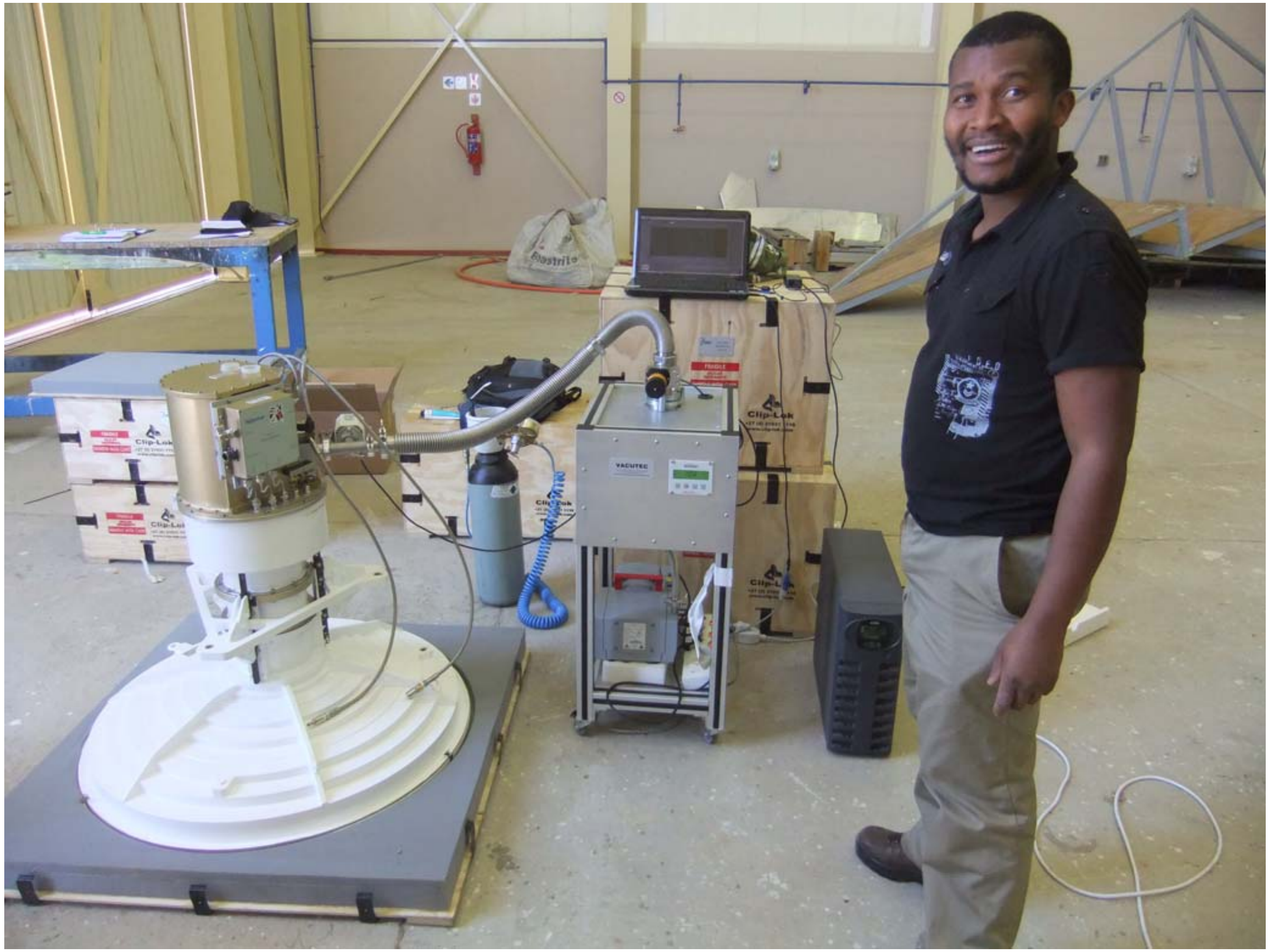
KAT-7 RX Installation



KAT-7 RX Installation

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KAT-7 RX Installation

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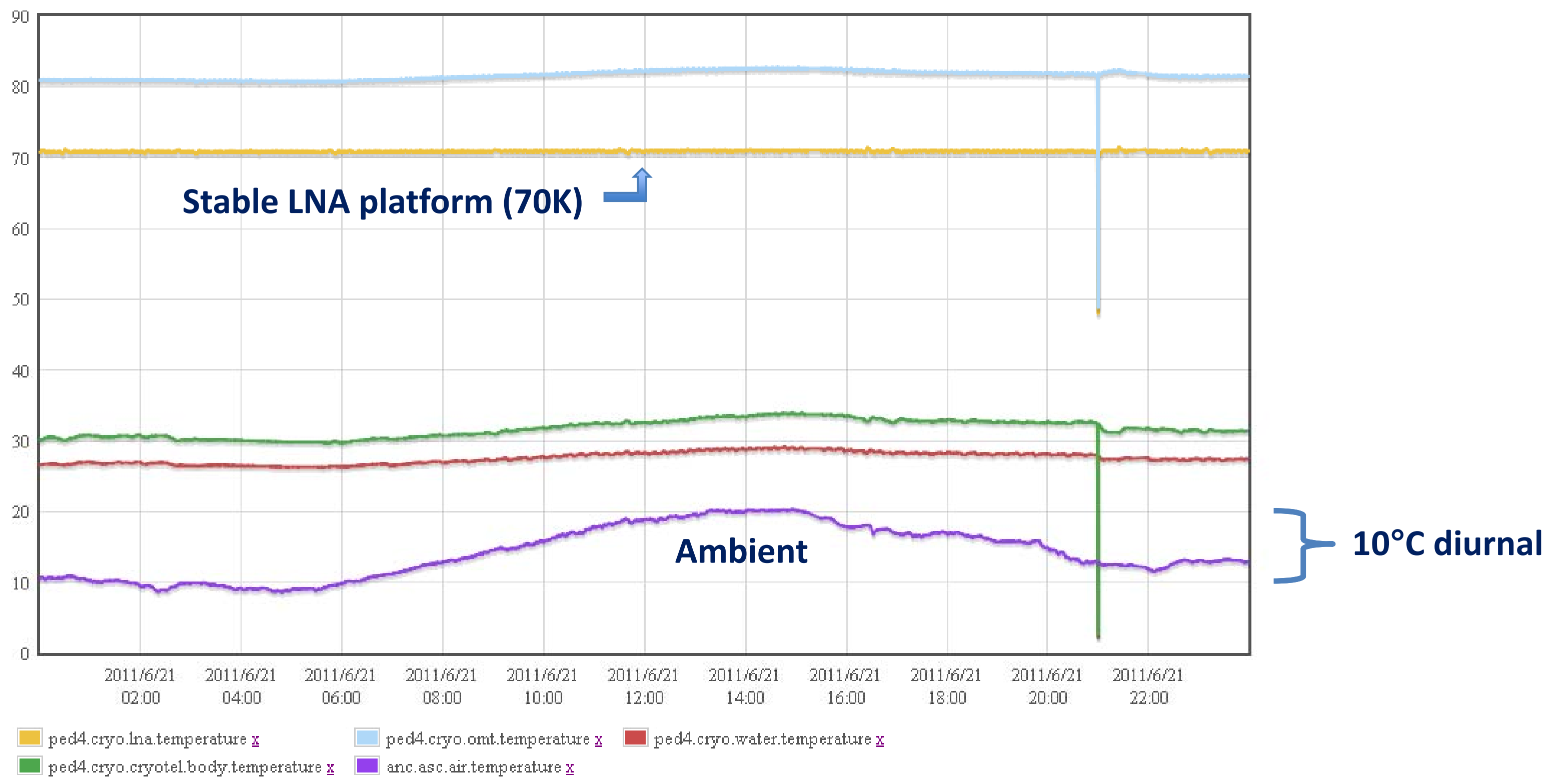
KAT-7 RX Installation (Mk.II)

KAT-7 Cryogenics Outcome

- Stirling can do science …
- … but vacuum maintenance may be problematic



KAT-7 Monitoring

KAT-7

List

Pause | Resume

Sensor Group: Custom on port 50008 (filter = ped[2,3,4,7]_cryo)

Sensor Name	Units	-	Antenna 2	Antenna 3	Antenna 4	Antenna 7	
Status indication		*09:44:01*	*(w)=warn*	*(e)=error*	*(f)=failure*	*(u)=unknown*	*or (other)*
agg__pedX_cryo_device_connected			1	1	1	1	
agg__pedX_cryo_device_synced			1	1	1	1	
pedX_cryo_15v_error			0	0	0	0	
pedX_cryo_48v_error			0	0	0	0	
pedX_cryo_address			192.168.209.10:6000	192.168.210.10:6000	192.168.211.10:6000	192.168.214.10:6000	
pedX_cryo_ambient_temperature	degC		18.80	19.30	20.50	19.20	
pedX_cryo_api_version			cryo-1.13	cryo-1.13	cryo-1.14	cryo-1.13	
pedX_cryo_build_state			cryo-Controller : 800-04453 Rev -1.13	cryo-Controller : 800-04453 Rev -1.13	cryo-Controller : 800-04453 Rev -1.14	cryo-Controller : 800-04453 Rev -1.13	
pedX_cryo_connected			1	1	1	1	
pedX_cryo_coolingfans_error			0	0	0	0	
pedX_cryo_cryotel_body_temperature	degC		32.50	33.10	30.50	32.50	
pedX_cryo_cryotel_coolingproblem			0	0	0	0	
pedX_cryo_cryotel_current	A		4.70	4.10	4.30	4.30	
pedX_cryo_cryotel_fuse_error			0	0	0	0	
pedX_cryo_cryotel_on			1	1	1	1	
pedX_cryo_ionpump_on			1	1	1	1	
pedX_cryo_ionpump_pressure	mbar		9.02e-06	(w) 1.17e-05	9.24e-06	(w) 1.25e-05	
pedX_cryo_lna_temperature	K		73.20	(e) 69.90	71.00	(e) 70.10	
pedX_cryo_omt_temperature	K		(e) 78.00	(e) 79.50	81.60	(e) 74.50	
pedX_cryo_state			synced	synced	synced	synced	
pedX_cryo_thermocouple_pressure	mbar		1.00e-04	1.00e-04	1.00e-04	1.00e-04	
pedX_cryo_vacuum_broken			0	0	0	0	
pedX_cryo_vacuum_too_high			0	0	0	0	
pedX_cryo_water_leak			0	0	0	0	
pedX_cryo_water_temperature	degC		22.80	20.80	26.40	22.40	

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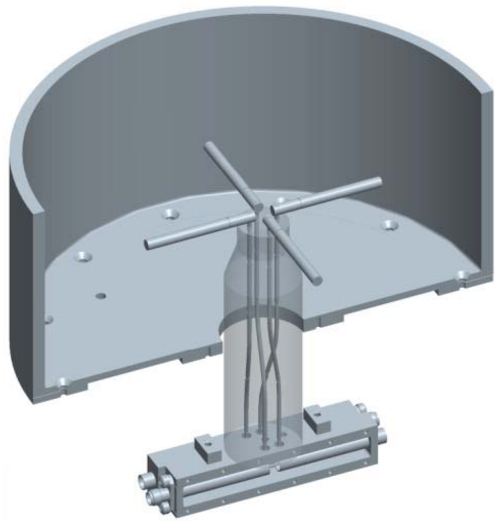
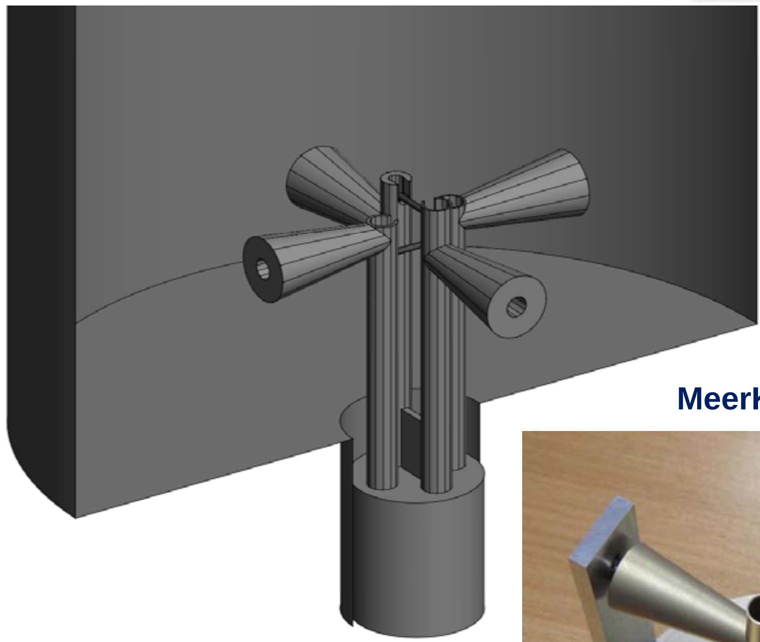
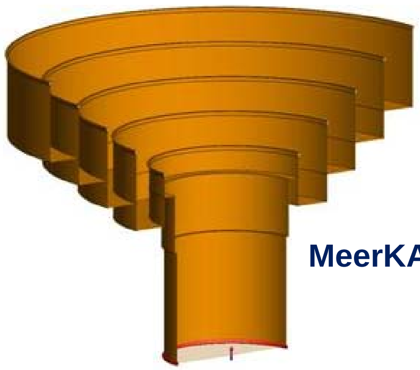
KAT-7 Building Blocks

Kat-7 (L-band)





MeerKAT (L-band)

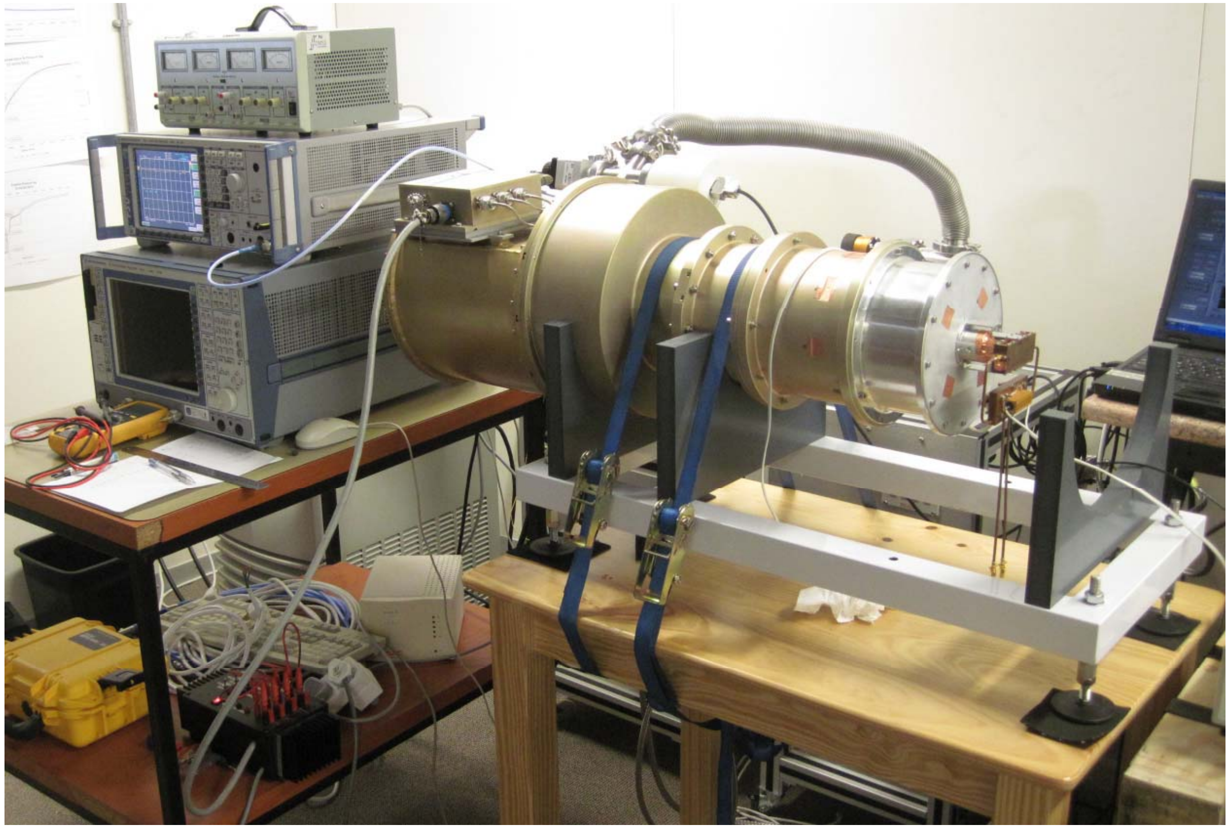


MeerKAT (L-band)

Noise Framework

	KAT-7 (Stirling, L-band, 1.6GHz)			MeerKAT (GM, L-band)	
	Predicted 2010	Measured 2011 [lab]	Measured 2011 [site]	Predicted 2011	Measured TBD
T_{CMB}	3.0 K			3 K	
T_{atm}	2.0 K			2 K	
$T_{horn\ \&\ dish}$	0.3 K			1 K	
$T_{foam\ vacuum\ window}$	0.7 K	Meas'd 16 to 20 K (Predicted = 18.0 K) [EA-K7-237-PTAS-01_2]		2K	
T_{OMT}	1.7 K				
$T_{coupler}$	4.1 K				
$T_{LNA\ feeder\ cable}$	1.5 K			-	
T_{LNA}	9.5 K			6 K	
$T_{RX\ safety\ margin}$	0.5 K			-	
$T_{post\text{-}LNA}$	1.0 K			2 K	
T_{spill}	5.0 K			4 K	
	29.3K		**24-29 K**	**20 K**	
	[EA-K7-237-PTAS-02_1]		[SET/TR/005/B]	[EA-MK-WP0012_1]	

Noise Framework



Noise Framework

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T_{OMT}	1.7 K				
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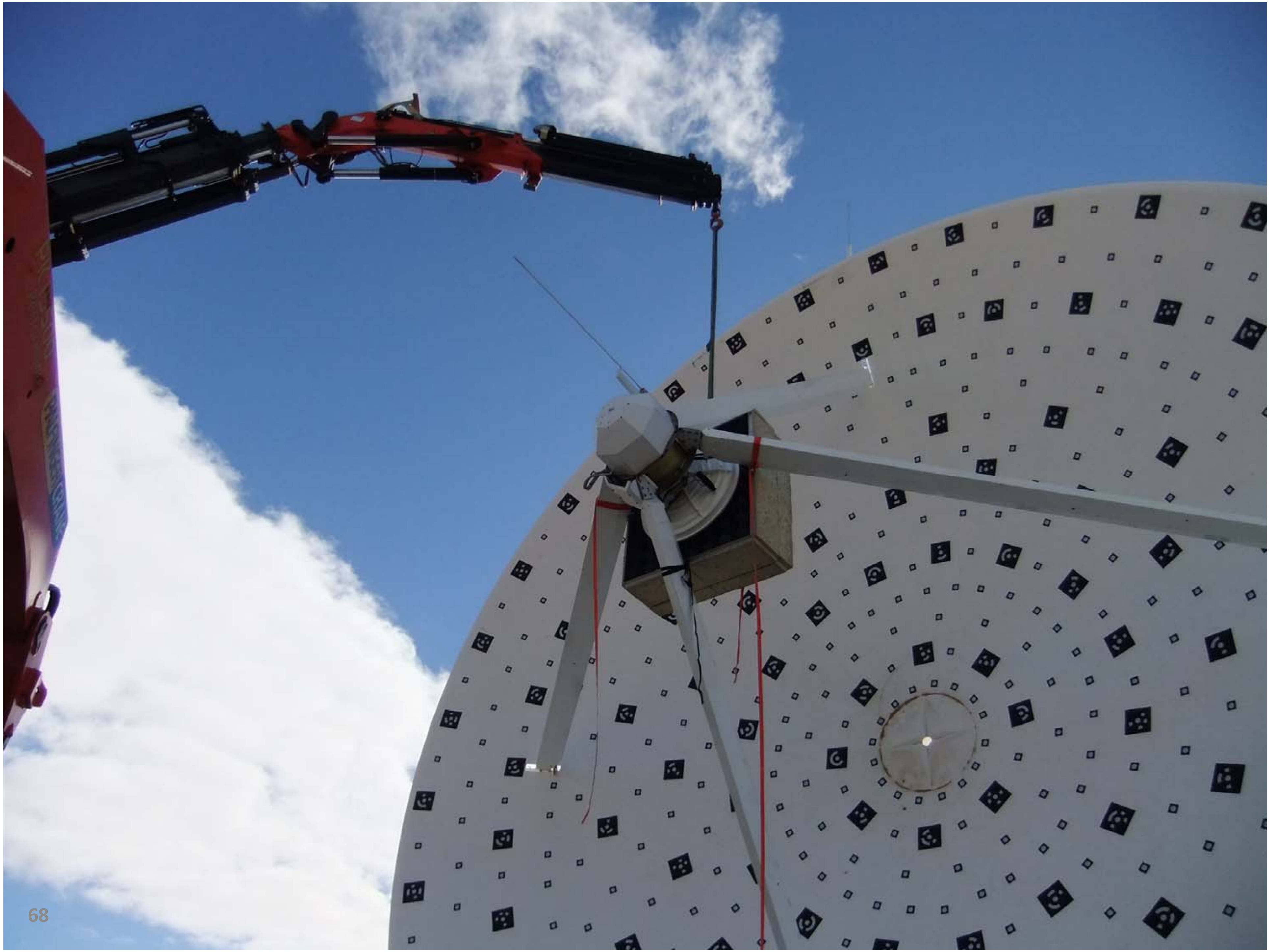

Noise Framework

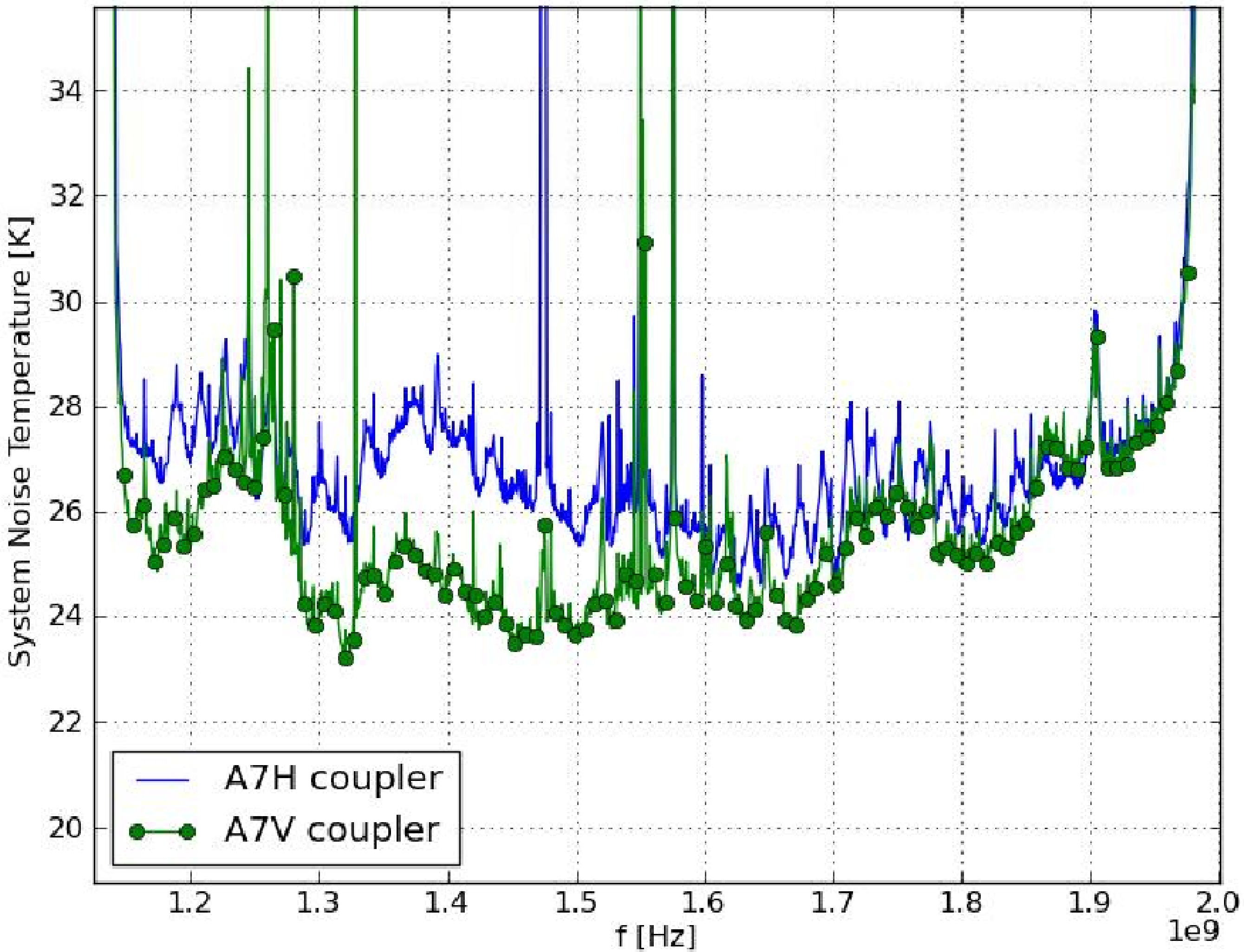

Figure 3: Tsys as measured at 30.72 deg elevation.

io telescope

Noise Framework

	KAT-7 (Stirling, L-band, 1.6GHz)			MeerKAT (GM, L-band)	
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T_{atm}	2.0 K			2 K	
$T_{horn\ \&\ dish}$	0.3 K			1 K	
$T_{foam\ vacuum\ window}$	0.7 K				
T_{OMT}	1.7 K	Meas'd 16 to 20 K		2K	
$T_{coupler}$	4.1 K				
$T_{LNA\ feeder\ cable}$	1.5 K	(Predicted = 18.0 K)		-	
T_{LNA}	9.5 K	[EA-K7-237-PTAS-01_2]		6 K	
$T_{RX\ safety\ margin}$	0.5 K			-	
$T_{post\text{-}LNA}$	1.0 K			2 K	
T_{spill}	5.0 K			4 K	
	29.3K		**24-29 K**	**20 K**	
	[EA-K7-237-PTAS-02_1]		**[SET/TR/005/B]**	**[EA-MK-WP0012_1]**	

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T_{OMT}	1.7 K				
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MeerKAT L-band Summary

- N = 64 Offset Gregorian
- Frequency coverage 1 to 1.75 GHz
- $T_{sys} \leq 20$ K (higher in UHF)
- $\eta_{all\text{-}up} > 66$ % (unshaped, lower at other frequencies)
- $A_{physical,single\text{-}dish} = 143\ m^2$
- **Sensitivity** > 300 [$m^2\ K^{-1}$]
- **$SSFoM_{-3dB}$** > 1.6×10^5 / $freq^2$ [$m^4\ K^{-2}\ deg^2$], freq in GHz

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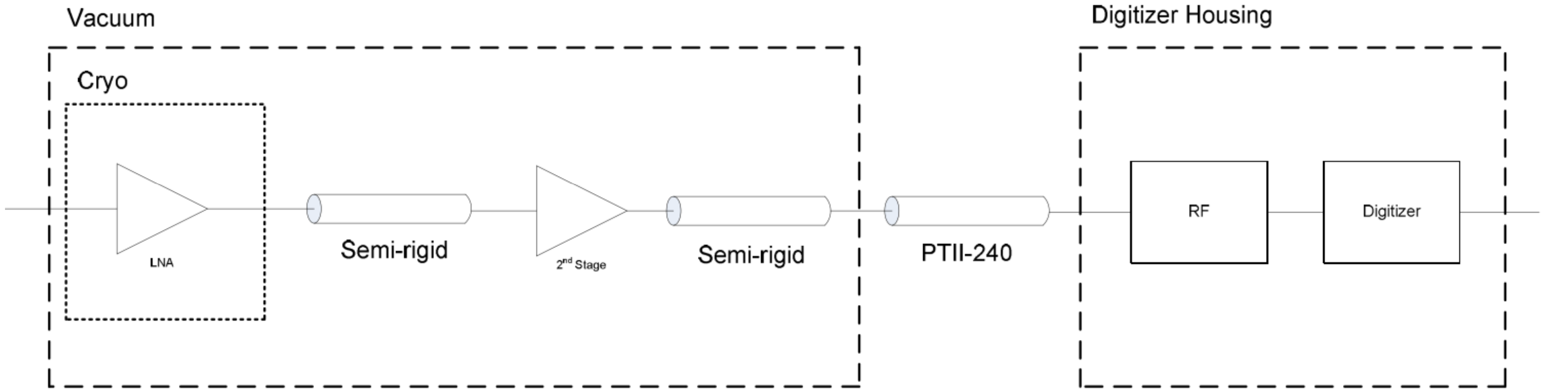
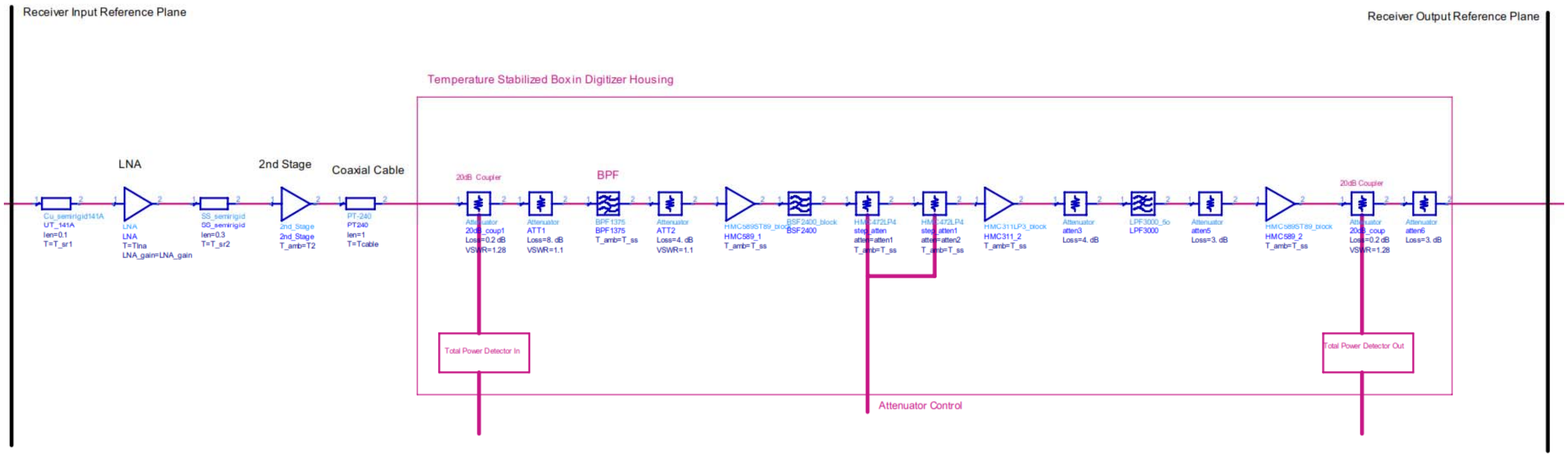
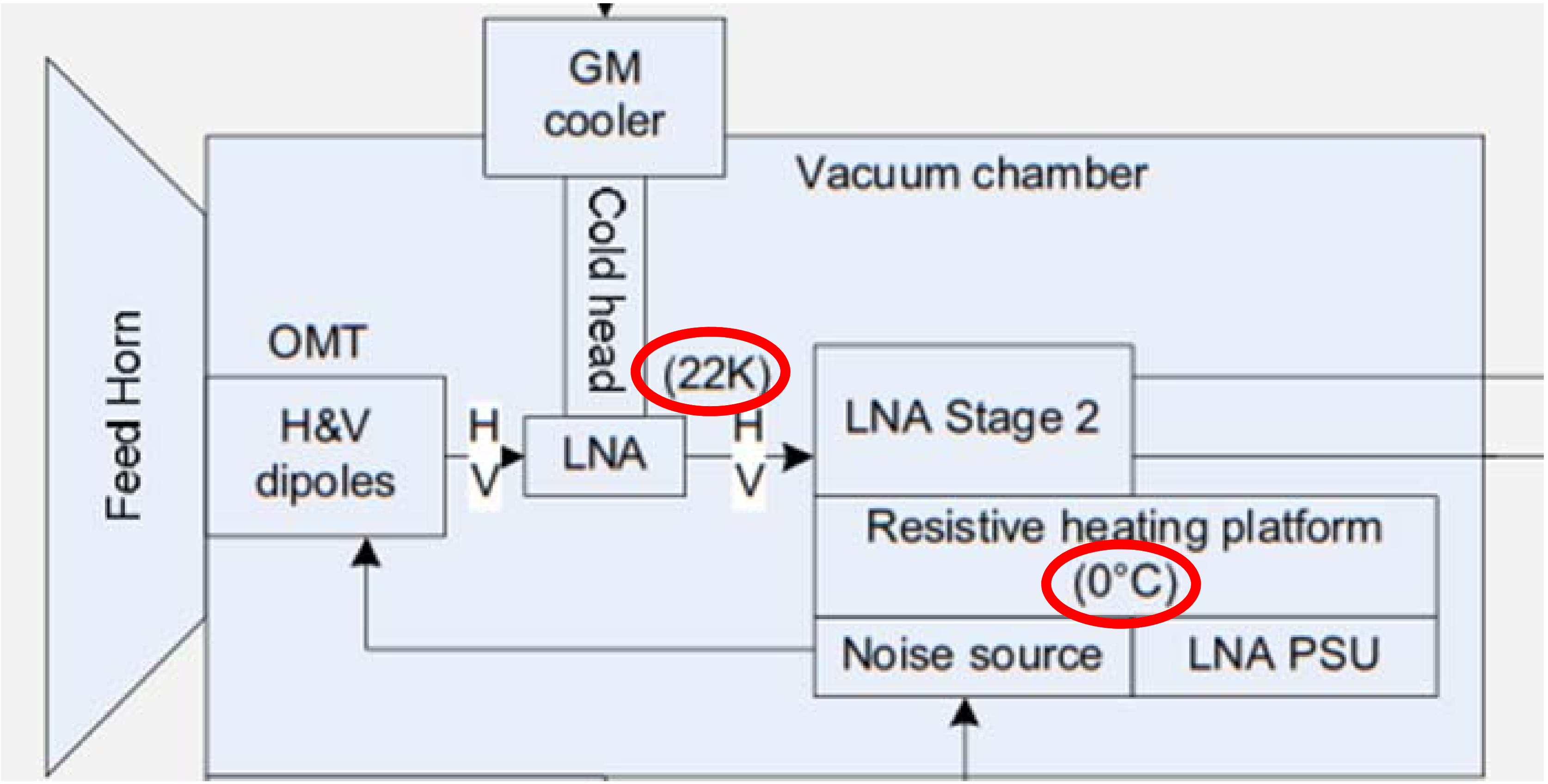
RF Chain & Allocation



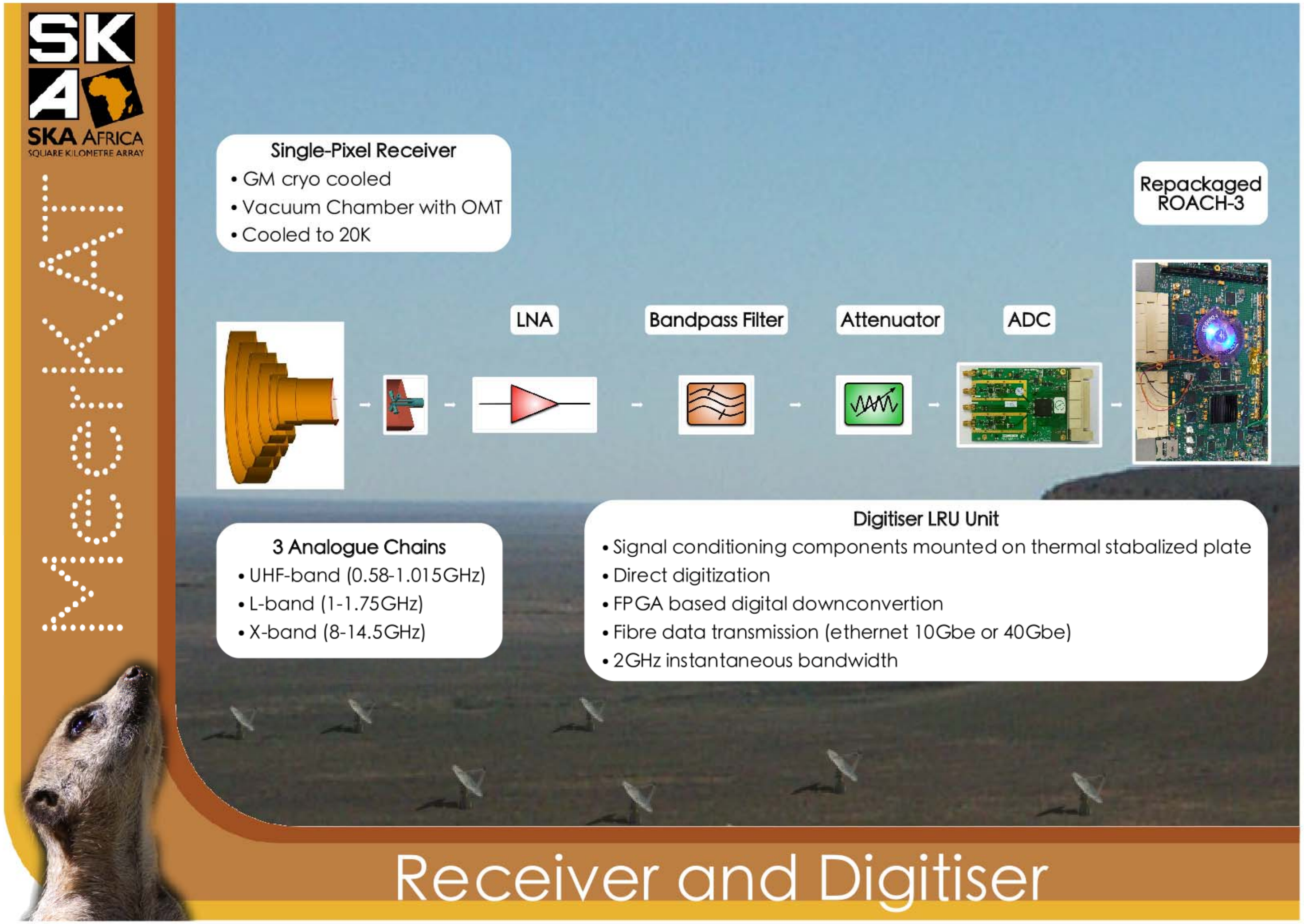


RF Chain – In Cryostat

- $G_1 + G_2 \sim 55dB$



RF & Digitiser



End

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