Optical Fibre Network for a Radio Astronomy Receiver

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science and technology

Department:
Science and Technology
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Workshop on Photonics in Radio Astronomy
Radionet Engineering Forum
Aviero, Portugal
Sep 2-3, 2010

Briefly, about me

Ooty Radio Telescope , India 1974-1985

http://ncra.tifr.res.in/ncra_hpage/ort/ort.html

- 530 m x 30 m parabolic cylinder
- On a hill with the slope same as the latitude;
- 1024 dipole linear array at 327 MHz

Giant Meterwave Radio Telescope , India 1985-2008

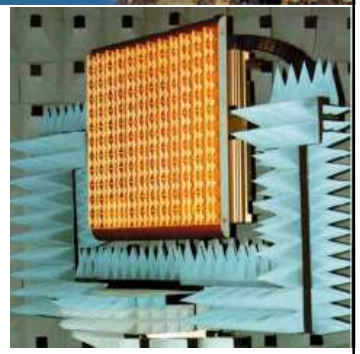
http://www.gmrt.ncra.tifr.res.in/

- 30 nos of 45m dia prime-focus dishes;
- Spread in an area with dia of 30 km;
- Operates in 150-1500 MHz band;
- 0.3 to 20 km analog optical fibre network for signal transport
- 80 km digital data link between Pune and GMRT with one repeater

Briefly, about me

One Square Meter Array (OSMA), ASTRON 1997-1999

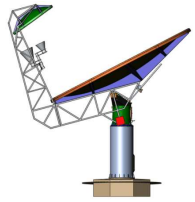
- Experimental Demonstrator towards an Electronically Steerable Radio Telescope
- 2 to 4 GHz RF; Beamforming with adaptive RFI cancellation



KAT-7, SKA-SA, South Africa 2008-

- South African precursor to SKA
- 7 prime focus antennas 12 m dia
- 200 m. baseline; 1.2-2 GHz RF
- Cryogenically cooled (77K) Front End
- 6 km analog optical network

meerKAT, SKA-SA, South Africa



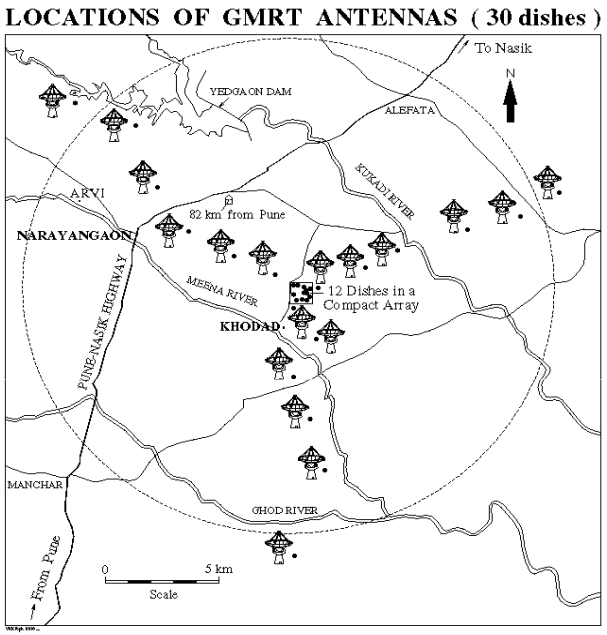
Abstract and Plan for the Talk

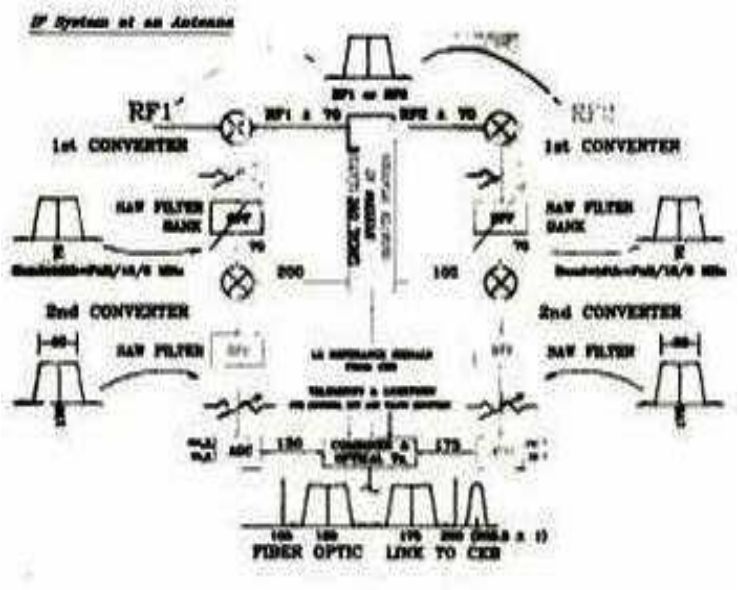
This presentation discusses the factors that go into the design of an analogue optical fibre network for a radio astronomy receiver. Such a network has been implemented for the KAT-7 phase of the SKA SA project, in order to transport the signal from seven antennas to a central node. The measured performance of the chosen optical transmitters and receivers is summarised, and on-going work for the signal transport of the 80-antenna MeerKAT array is presented.

PLAN:

- ➢GMRT PHOTONICS
- KAT-7 PHOTONICS
- ❑meerKAT PHOTONICS

GMRT Photonics

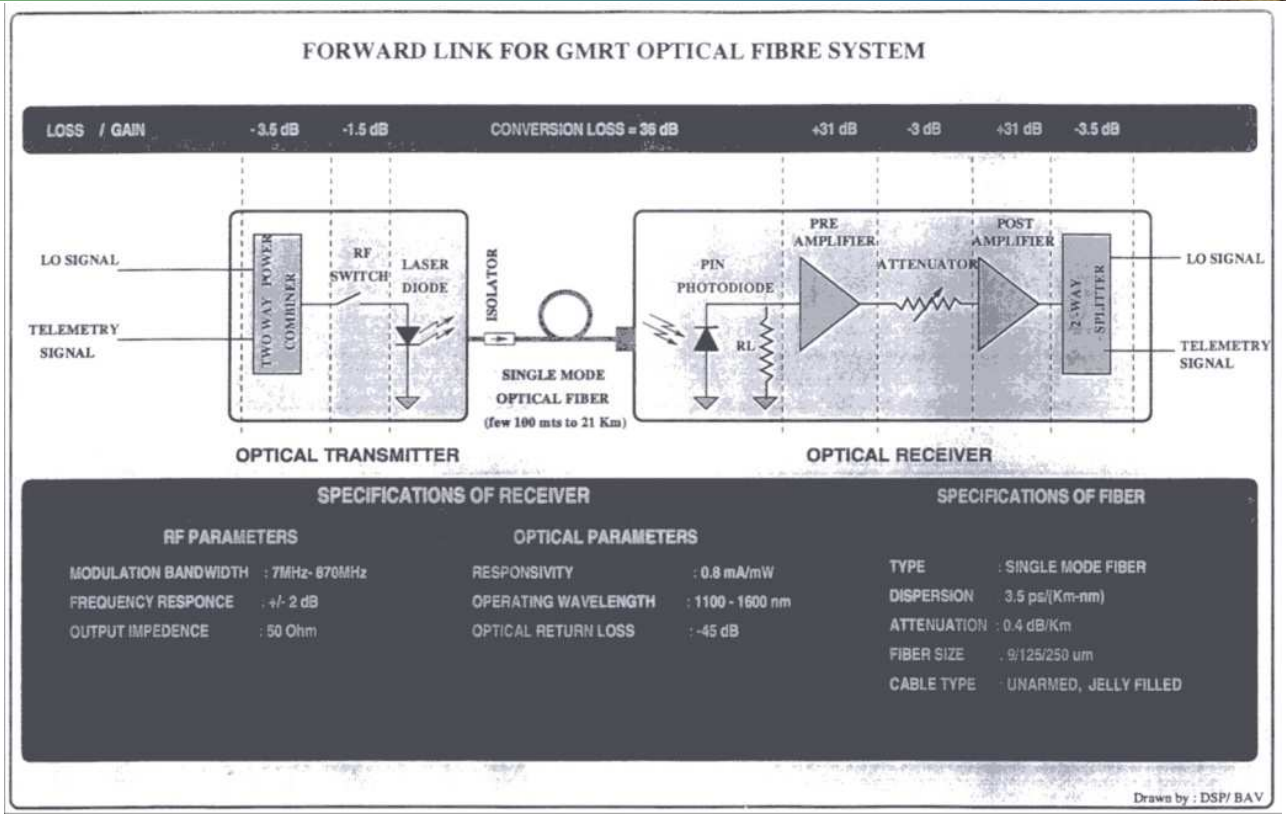




- **Two fibres to each antenna from the Central Electronics Building**

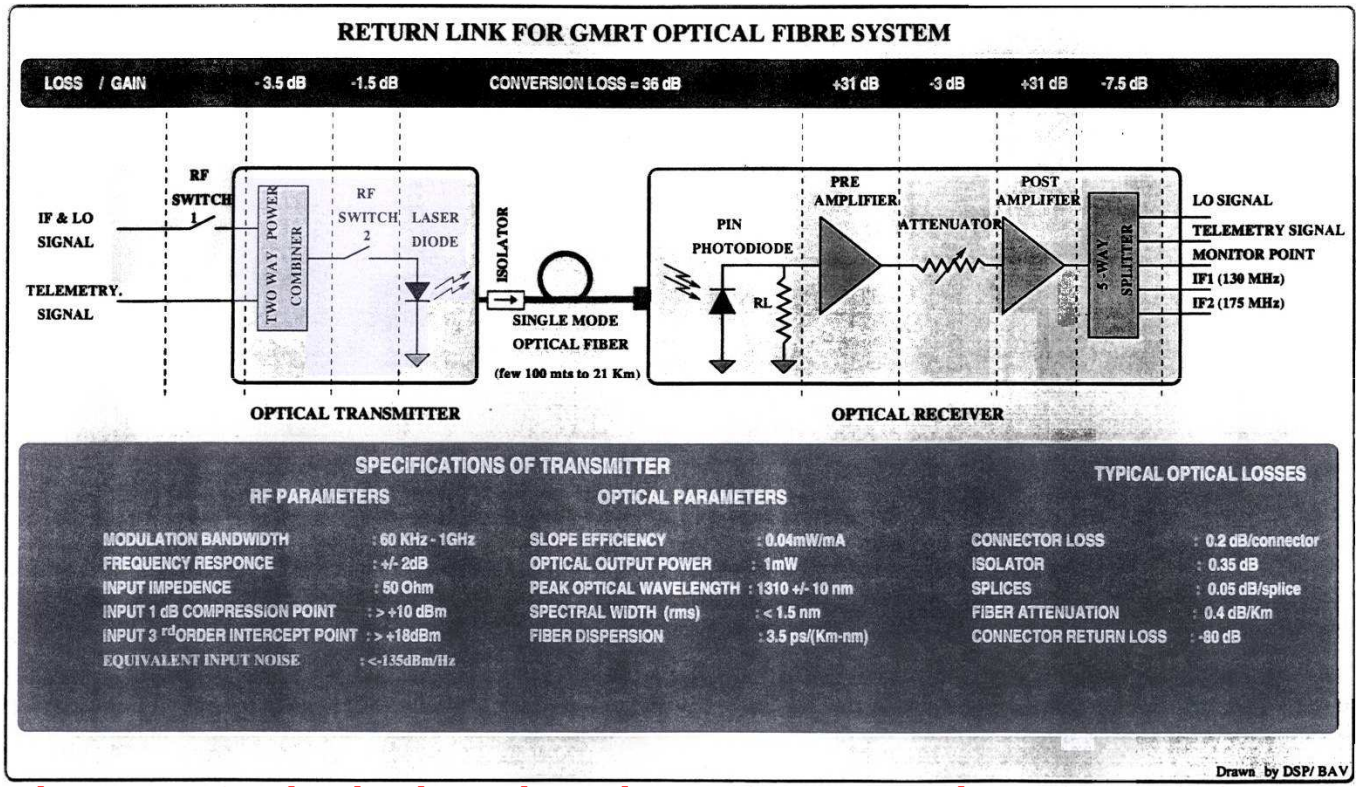
- **The scope of the Analog OF Network is to "pack" the signals handled in the return link from each antenna within an octave band of 105-210 MHz – *TECHNOLOGICAL MILESTONE IN EARLY 1990s***

GMRT Photonics



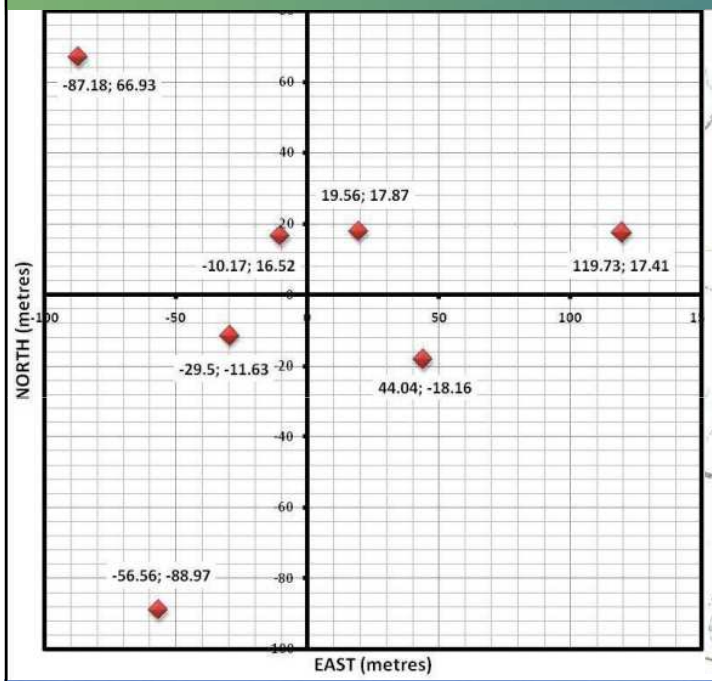
Forward link transmits a pair of LO Reference Signals at 105 and 200 MHz as well as Telemetry FSK signal around 18 MHz

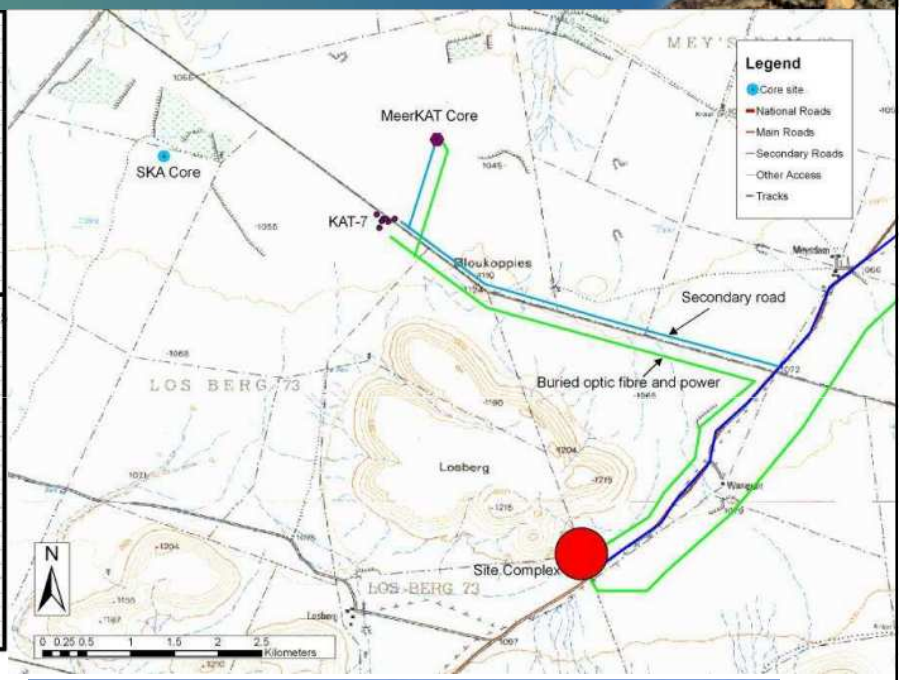
GMRT Photonics



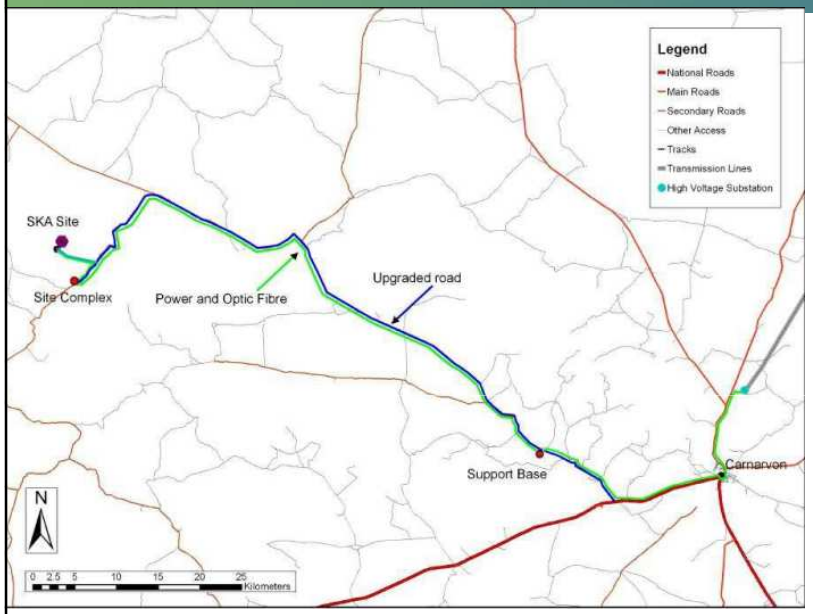
In-house R&D in the last decade on CWDM and 1550 nm 3 GHz Tx-Rx links have led to the EXISTING 2-fibre link support BOTH the "old" as well as Upgraded broad-band Systems simultaneously

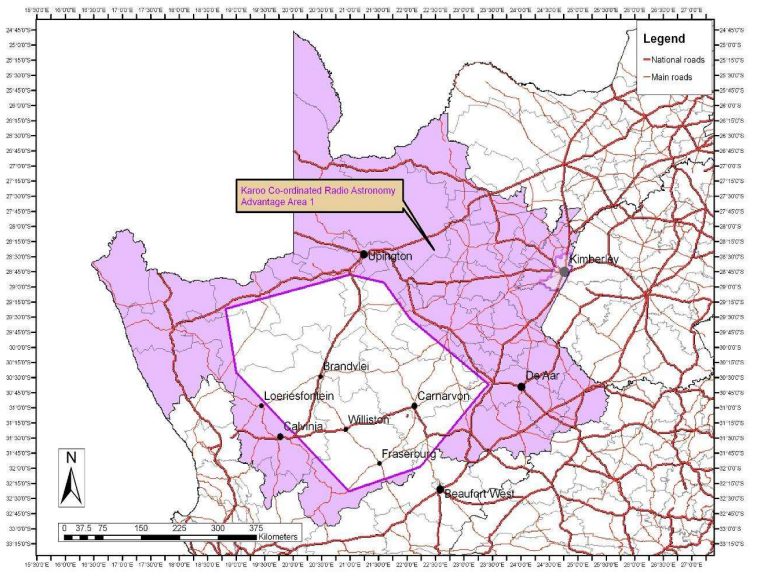
The KAT-7, meerKAT and SKA Array Cores





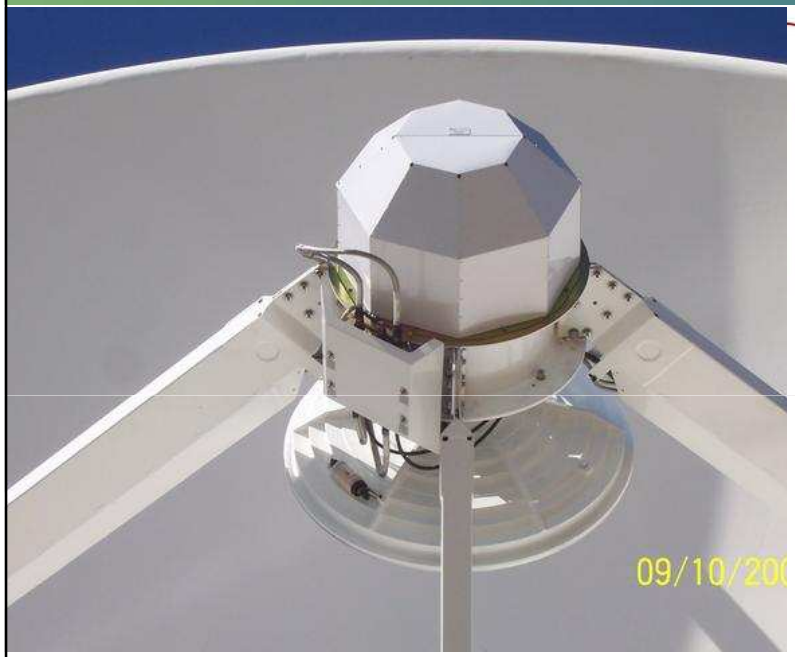
The SKA-SA AGA Act Area

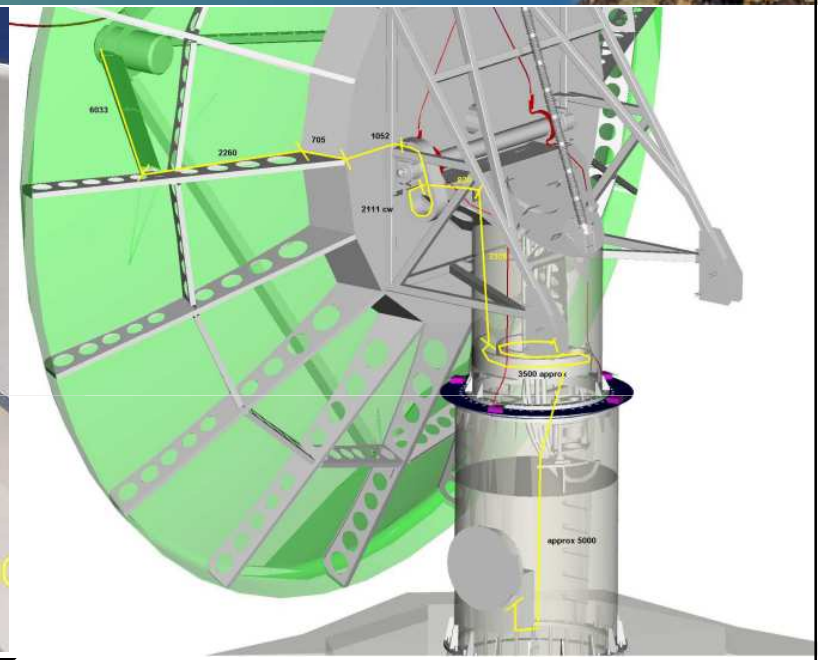


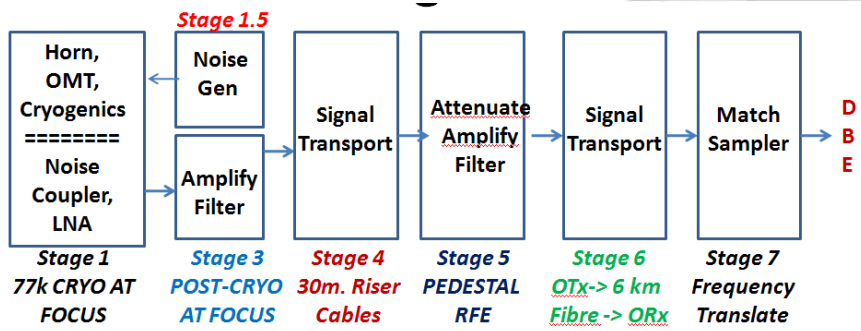


AGA Act: Astronomy Geography Advantage Act

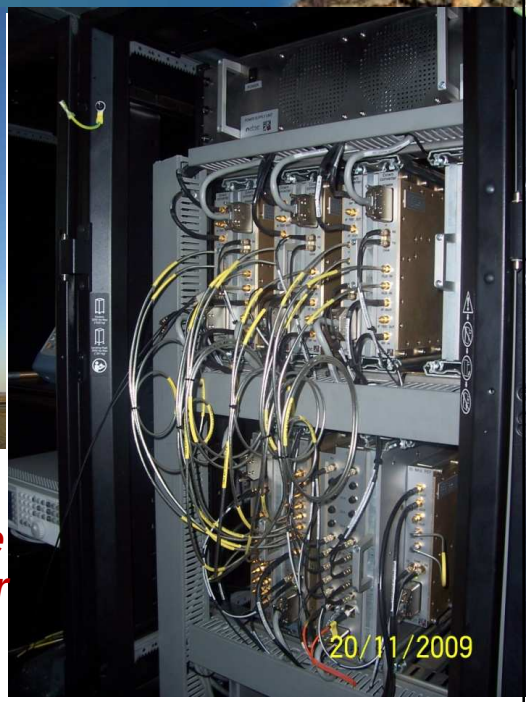
The Stages of KAT-7 Receiver



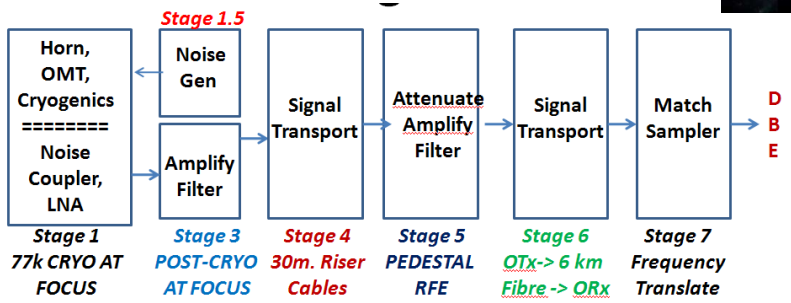




The Stages of KAT-7 Receiver



The KAT-7 system has been designed with an ability to survive a continuous -44 dBm input power at LNA terminals with out damage



The KAT-7 Receiver: Overall Performance

BUDGET UPDATE FORMAT FOR GAIN

Nominal Input power -95 dBm; Output power -27 dBm implies 68 dB typical RFE gain

	STAGE 1	STAGE 3	STAGE 4	STAGE 5	STAGE 6	STAGE 7	RFE
seed	38 dB	10 dB	-10 dB	10 dB	10 dB	10 dB	68 dB
PDR figures	38 dB	22 ±1dB (Tellumat)	PDR Decisions needed	5 ±1 dB (at 5 dB attr setting: Tellumat)	RFP outcome awaited	10 dB (at 0 dB attr setting: ETSE)	
Apr 28 update	<37.6±?> Tests planned in Cryo at EMSS*	22± 1 dB	-6 dB for FS400**	-5 ±1 dB at 5 dB nominal attenuator setting	<10±3> CDR May 1st week	10 dB at 5 dB nominal attenuator setting	68.6 dB (FS400)
Final Figures	37.6±1 dB	22± 1 dB	-6 dB for FS400**	-5 ±1 dB at 5 dB nominal attenuator setting	Variable Gain*** to give -37 dBm output	10 dB at 5 dB nominal attenuator setting	68 dB

•Room temperature measurements are satisfactory and match data sheet. Statistical data comparing performance at 77K of 8 amplifiers for KAT-7 in final testing at MITEQ Factory is expected shortly. Assumes pre-LNA losses from the CDR report of EMSS

*** 27 meters cable length assumed. Nominal Figures at mid-band given. Loss Slope across RF band is ±0.75 dB for FS400*

**** By adjusting potentiometer in Optical Receiver LRU*

The KAT-7 Receiver: Overall Performance

Cascaded RFE Study for Receiver Temperature and Head-room

Notes: Parmeters in RED are input parameters Parameters in BLACK are derived. Ver A Mar 15, 2k9 Ver B Apr 13, 2k9 Ver C Apr 28, 2k9 Ver D Jul 22, 2k9																				
			physical temp		77															
BASIC SPECS AT EACH BLOCK:	OMT OUT		Barrel		Dir Cplr		Cable		LNA		Stage 3		Stage 4		Stage 5		Stage 6		Stage 7		DBE	
1 dB compression point at input (dBm)		*1000*		*1000*		*1000*		*38*		*8*		*1000*		*4*		*-10*		*0*		------		------
1 dB compression point at output (dBm)		*1000*		*1000*		*1000*		*1000*		*0*		------		*1000*		------		------		*10*		------
IP3 at input (dBm)		*1000*		*1000*		*1000*		------		*2*		*1000*		*6*		*0*		10		------		------
IP3 at output (dBm)		*1000*		*1000*		*1000*		*1000*		------		------		*1000*		------		------		------		------
Noise Figure at input (dB)		0.026		0.052		0.033		*0.15*		*9*		*6*		*15*		*16*		*19*		------		------
Gain for RF Signal (dB)			*-0.1*		*-0.2*		*-0.125*		*38*		*22*		*-6*		*-5*		*11.37*		*10*		------	
Cumulative Gain at a Point:																						
Cumulative RF Signal Gain (dB)		*0*		-0.1		-0.3		-0.425		37.575		59.575		53.575		48.575		59.945		------		
POWER AT EACH BLOCK OUTPUT (in dBm):																						
Nominal power in a 1.2-1.95 GHz bw (T = Row 50)		-96.945		-97.045		-97.245		-97.370		-59.370		-37.370		-43.370		-48.370		-37.000		------		
NOISE TEMPERATURE T (in K):																						
At a point in the receiver chain		1.763		3.507		2.201		10.191		2013.552		864.511		8880.605		11255.108		22745.519		------		
Individual Block Contribution at input		1.763		3.589		2.359		11.239		0.352		0.001		0.039		0.156		0.023		------		
Total Noise at input (K)		*19.521*																				
Head room to 1 dB compression at INPUT of each block		*1096.945*		*1097.045*		*1097.245*		*59.370*		*51.370*		*1037.370*		*39.370*		*38.370*		*37.000*		------		

LOSS MINIMISATION EFFORTS IN PROGRESS!

STAGE 4 OTHER DETAILS: Flexstrand FS600 DB from Times Microwave used for above calculations

STAGE 5 OTHER DETAILS: Nominal Attenuation Setting: 5 dB Gain adjustable from 0 to 63 dB in 0.5 dB steps

STAGE 7 OTHER DETAILS: Nominal Attenuation Setting: 5 dB Gain adjustable from 0 to 15 dB in 1 dB steps

The KAT-7 Receiver: Overall Performance

BUDGET UPDATE FORMAT FOR NOISE FIGURE

	STAGE 1	STAGE 3	STAGE 4	STAGE 5	STAGE 6	STAGE 7	RFE
seed	<=0.3 dB		<= 10dB		<=12 dB		<=15K (goal 10K)
PDR figures	Could be lowered at considerable expense!	12 dB (Tellumat)	PDR Decisions needed	31 dB (Tellumat)	RFP outcome awaited	8 dB (ETSE)	
Apr 28 update	Tests planned in Cryo chamber at EMSS*	9 dB	6 dB for FS400	15 dB	<12 dB> CDR May 1st week	23 dB	~20K**
Final figures	**0.3 dB**	**9 dB**	**6 dB**	**15 dB**	**16 dB*****	**19 dB**	**<=20K (goal 17K)**

* *Room temperature measurements are satisfactory and match data sheet. Statistical data comparing performance at 77K of 8 amplifiers for KAT-7 in final testing at MITEQ Factory is expected shortly.*

** *Pre-LNA Loss Minimisation efforts are in progress.: Not very successful.*

*** *For a setting of -10 dBm as 1 dB compression point in the Optical Transmitter LRU*

The KAT-7 Receiver: Overall Performance

BUDGET UPDATE FORMAT FOR HEADROOM TO 1 dB COMPRESSION

	STAGE 1	STAGE 3	STAGE 4	STAGE 5	STAGE 6	STAGE 7	RFE
seed	26 dB (goal 34 dB)	26 dB (goal 34 dB)	26 dB (goal 34 dB)	26 dB (goal 34 dB)	16 dB (goal 34 dB)	26 dB (goal 34 dB)	26 dB (goal 34 dB)
PDR figures	Goal will be met	Spec will be met (Input IP3 of +2 dBm expected)	Passive; Goal will be met	Spec will be met (Input IP3 of +6 dBm expected)	RFP outcome awaited	26 dB (goal 34 dB)	
Apr 28 update	59.4 dB	51.4 dB	No issues	38.4 dB	<37 dB> CDR May 1st week	37 dB	***STATUS REMAINS!***
Final figures	59.4 dB	51.4 dB	No issues	38.4 dB	38 dB	37 dB	Goal met

From EVLA memo 110, a 1% Gain Compression point is derived, which is 14 dB below the 1 dB compression point. The Goal for the RFE has been set as 20 dB headroom to 1% compression point

The KAT-7 Receiver: Overall Performance

BUDGET UPDATE FORMAT FOR GAIN FLATNESS (256 MHz)

	STAGE 1	STAGE 3	STAGE 4	STAGE 5	STAGE 6	STAGE 7	RFE
seed	0.4 dB p-p (goal 0.2 dB)	0.4 dB p-p (goal 0.2 dB)	0.4 dB p-p (goal 0.2 dB)	0.4 dB p-p (goal 0.2 dB)	0.4 dB p-p (goal 0.2 dB)	0.4 dB p-p (goal 0.2 dB)	2 dB p-p (goal 1 dB)
PDR figures	To be measured	1 dB p-p	PDR Decisions needed	1 dB p-p	RFP outcome awaited	2 dB p-p (goal 1 dB)	
Apr 28 update	Tests in Cryo chamber at EMSS scheduled	<= 1 dB pp	0.61 dB for FS400; 0.45 dB for FS600; 0.8 dB for RG214	<=1 dB pp	<0.4 dB p-p> CDR May 1st week	0.8 dB, excluding mixer simulation	
Final figures	**<=1 dB pp**	**<= 1 dB pp**	**0.6 dB pp**	**<=1 dB pp**	**0.4 dB pp**	**1.2 dB pp (goal 1 dB)**	**6 dB pp (Goal 5 dB) ***

*** Might need to add an Equaliser ?**

The KAT-7 Receiver: Overall Performance

BUDGET UPDATE FORMAT FOR GAIN STABILITY

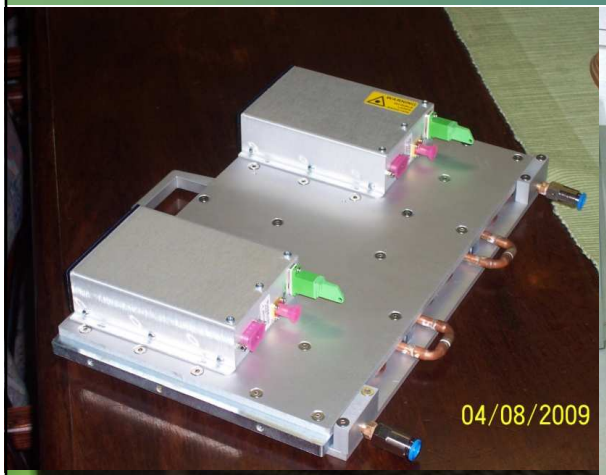
	STAGE 1	STAGE 3	STAGE 4	STAGE 5	STAGE 6	STAGE 7	RFE
seed	0.25% RMS over 10 minutes	0.25% RMS over 10 minutes	0.25% RMS over 10 minutes	0.25% RMS over 10 minutes	0.25% RMS over 10 minutes	0.25% RMS over 10 minutes	1.5% RMS over 10 minutes
PDR figures	Data not available; May be expensive to get	± 0.025 dB over 10 minutes	PDR Decisions needed	± 0.025 dB over 10 minutes	RFP outcome awaited	<TBD> with goal of 0.01 dB over 10 minutes	
Apr 28 update	Tests in Cryo chamber at EMSS scheduled	± 0.025 dB in 10 minutes*	0.01 dB for a ΔT of 5 deg C**	± 0.015 dB In 10 minutes *	CDR May 1st week	*0.27% in 10 minutes* *for cold plate temp of 25±1° C*	
Jul 22 figures							

* Discussions with Mario on March 15, 2k9

** Assumes a third of the Flexstrand 400 cable length of 27 m. is exposed directly to sunlight and is subjected to a 5deg C temp change in 10 minutes. Based on measurements done at facilities in Tellumat. Special enclosure needs to be designed and built for getting similar numbers on FS600. For the first order, same performance may be assumed.

Recent controlled verifications of stability of a typical Stage 3 Unit shows that the target is met and CAN be improved further if desired by a re-design of the enclosure.

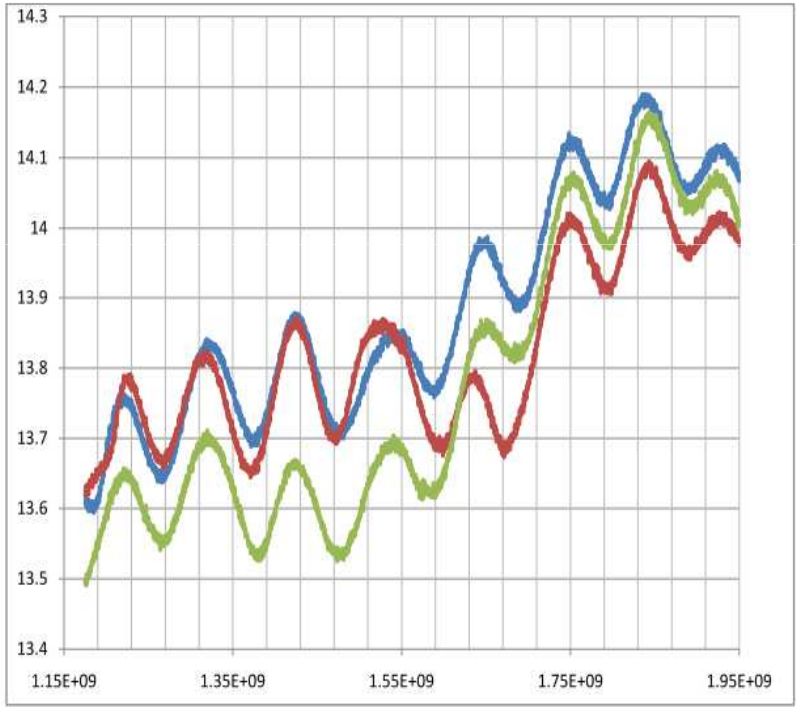
The KAT-7 Optical Transmitter and Receiver

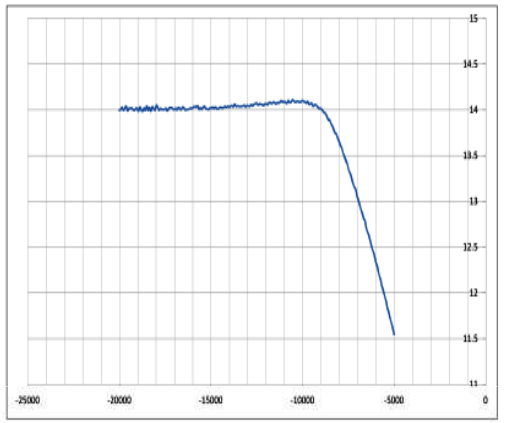


- Contract awarded o FOXCOM, Israel
- Standard 7310 series units (10-2500 MHz; Repeater-less 15 km operation) tweaked individually to meet SKA-SA specifications
- Transmitter has an Adjust Pot to set 1 dB Compression Point
- Receiver has an Adjust Pot to set net RF Gain of OTx-ORx pair
- Built-in power detectors help to set both points conveniently

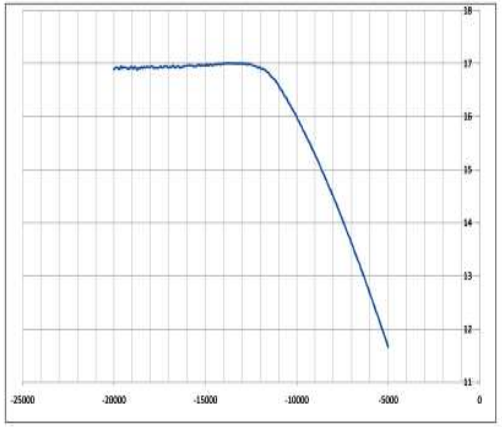
The KAT-7 Optical Transmitter and Receiver

Gain response comparison of three independent pairs of Transmitters and Receivers under similar settings of 1 dB compression and gain





1 dB compression point
Adjusted to -7 dBm to give
14 dB gain



Adjusted to -10 dBm
with 17 dB gain. Rx pot is
not touched

Plots with 1m. Fibre. Similar ripple and p-p performance with a 10 km fibre spool

The OTx and ORx: Measured Performance

For ± 3 dB gain setting around a nominal gain of 17 dB (7 dB RF loss due to 6 km cable assumed, to give a typical installation link gain of 10 dB) and a FIXED 1 dB compression setting of -10 dBm

- Tx Draws 200 mA from 8V and 100 mA from -5.5V rails
  - Power Supply Coefficient on gain: ±0.05 dB/ 12±1V
    ±0.03 dB/ -5.5±0.3V
  - Power Supply Coefficient on group delay: not measurable
- Rx draws 250 mA from 12V nominal
  - Power Supply Coefficient on gain: ± 0.01 dB/ 12±1 V
  - Power Supply Coefficient on group delay: not measurable

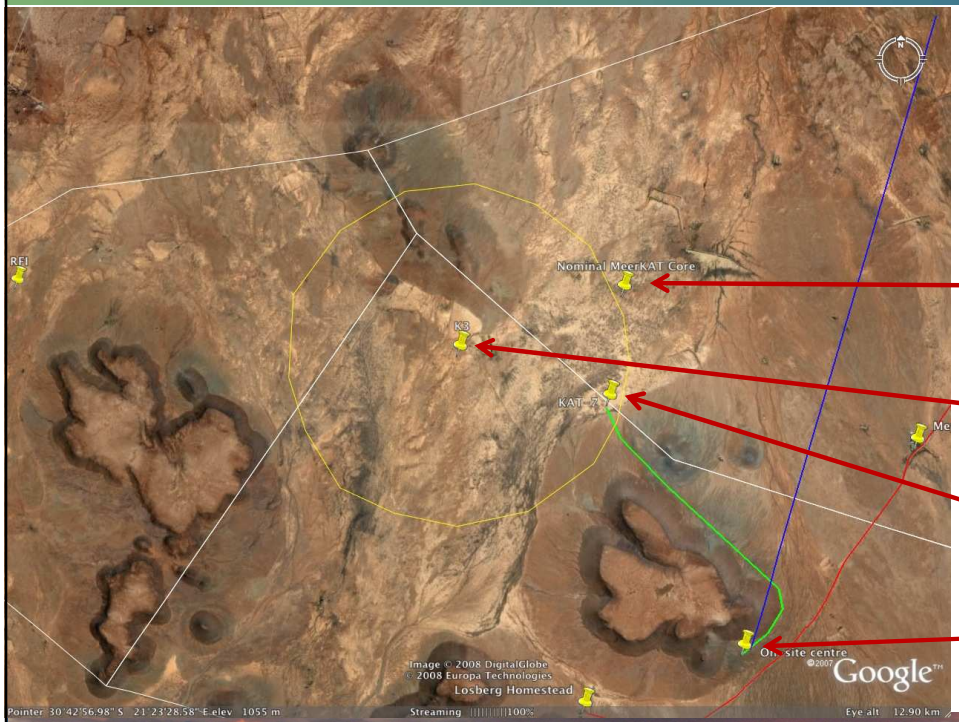
- Gain stability with temperature: ±0.004 dB/ deg C, over 0-40 deg C
- Group delay stability with temperature: Not measurable

The OTx and ORx: Measured Performance

- Input return loss: Better than 18 dB
- Output return loss: Better than19 dB
- Noise Figure: 16 dB
- SNR: 30 dB in 1 GHz bandwidth
- OIP3: +16 dBm
- IMD products at -19 dBm inputs: -97 dB
- RFI Compliance tested to MIL-STD 461E RE102 at the facilities of ISSA, Houwteq, South Africa
- No damage after 2 minutes of an in-band input at +15 dBm

NOW FOR THE NEXT CHALLENGE!

The meerKAT Receiver: ESSENTIALS



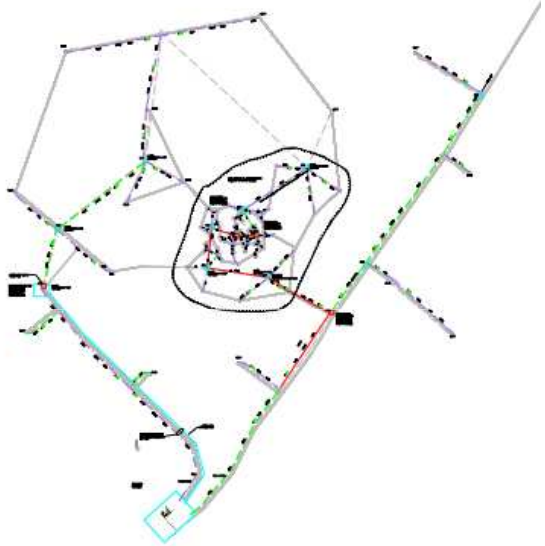
meerKAT Core

SKA Core

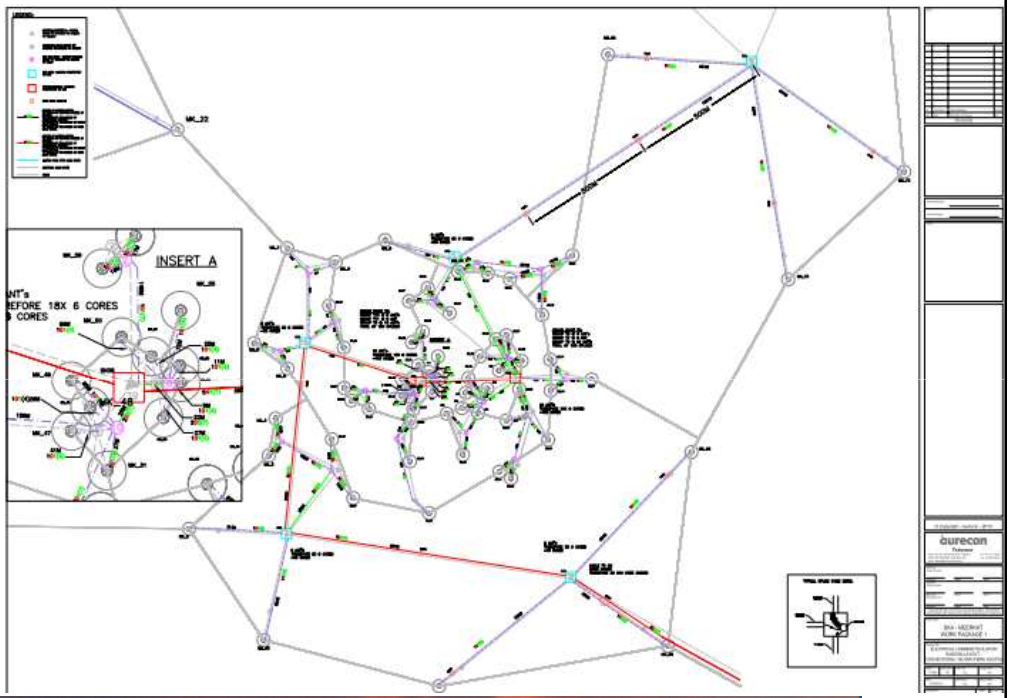
KAT-7

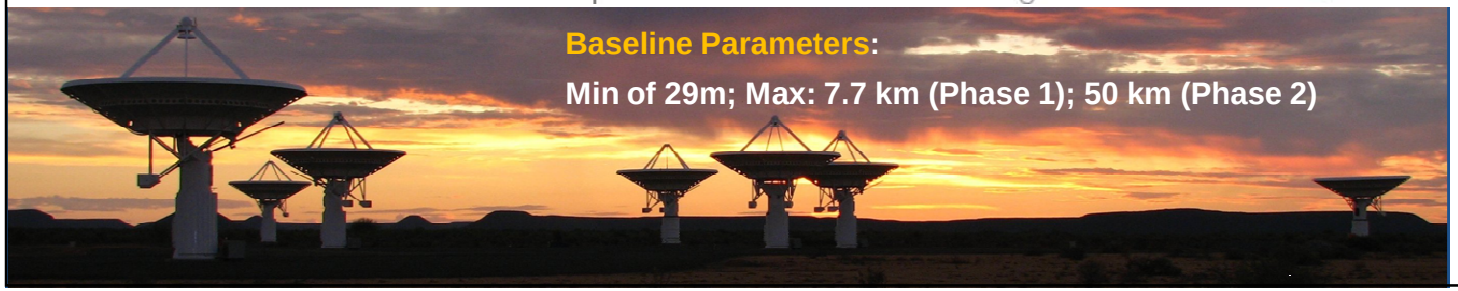
Site Facility

The meerKAT Receiver: ESSENTIALS



Site Facility





Baseline Parameters:

Min of 29m; Max: 7.7 km (Phase 1); 50 km (Phase 2)

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The meerKAT Receiver: ESSENTIALS

PRIMARY SCIENCE DRIVERS:

RF Band coverage : (a) 0.59 to 2.4 GHz (b) 8 to 15 GHz

Sensitivity (A_e/ T_{sys}) : 220 m^2/ K with T_{sys} of 27K in L-band

Dynamic Range : 300 000 to 1 with FOV of 1 deg^2 in L-band

OPTIONS TO MEET THE DRIVERS:

Choice of Dish : (a) CENTRE FED PRIME FOCUS

(1mm surface; 15" pointing accuracy): ***(b) OFFSET GREGORIAN***

No. of antennas : ***(a) 64*** OR (b) 80 in Central Cluster

(60 kmph stow; 15 to 95 deg elevation): 7 antennas in a spur 80 km long (PHASE 2)

Digitisation location : (a) Central Node ***(b) Focus of antenna***

Diameter : (a) 12 m. ***(b) 13.5 m*** (c) 14.7 m.

Feed Element : ***(a) 2 to 1*** (b) 4 to 1 (c) broader bandwidth

The meerKAT Receiver: ESSENTIALS

- Swappable Octave band Single pixel Cryo Receivers at focus with indexing mechanism to choose 2 or 4 feeds
- LNAs and Noise sources in 77K environment
- All RF functionalities (filter/ level control/ total power detector) inside the “EM IN-RF OUT” package
- The Analog or ***ADC+Digital Optical Transmitter*** located at focus to take outputs from ALL cryo receivers via ~1m coax
- Phased Approach to reach the Goal:

(a) 900-1750 MHz (b) 590-1100 MHz (c) 8 to 15 GHz for ***(a) 10 km*** (b) 50 km (c) 50 km baselines by ***(a) 2014***, (b) 2016 (c) 2017 respectively

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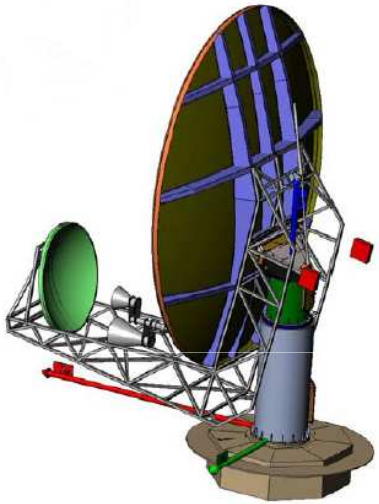
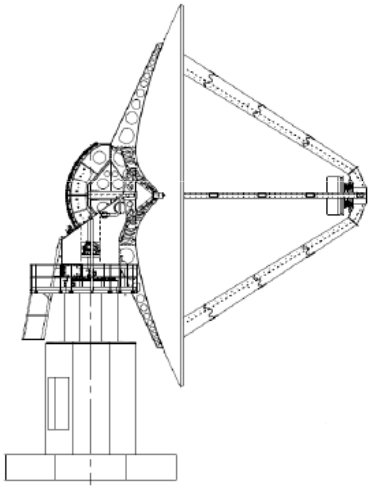
The meerKAT Optonics: Requirements

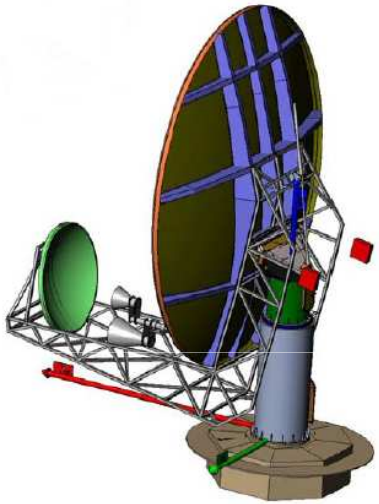


Functionalities to be supported

- Digitised Dual-Linear-Polarised astronomical signal transport over ~10 kms (in phase 1) and ~80 kms (Phase 2)
- Round Trip Phase estimation
- Clock distribution for ADC sampling
- Control and Monitor (CAM) of Receiver, Antenna Motion, estate management etc

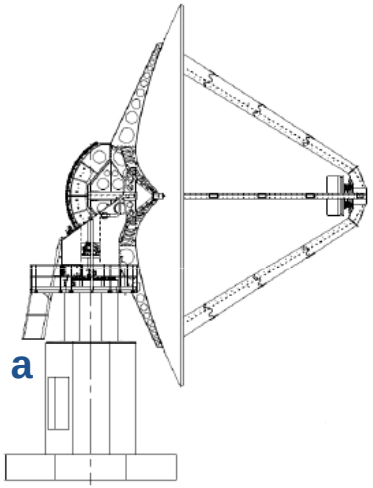


The meerKAT Optonics: Issues

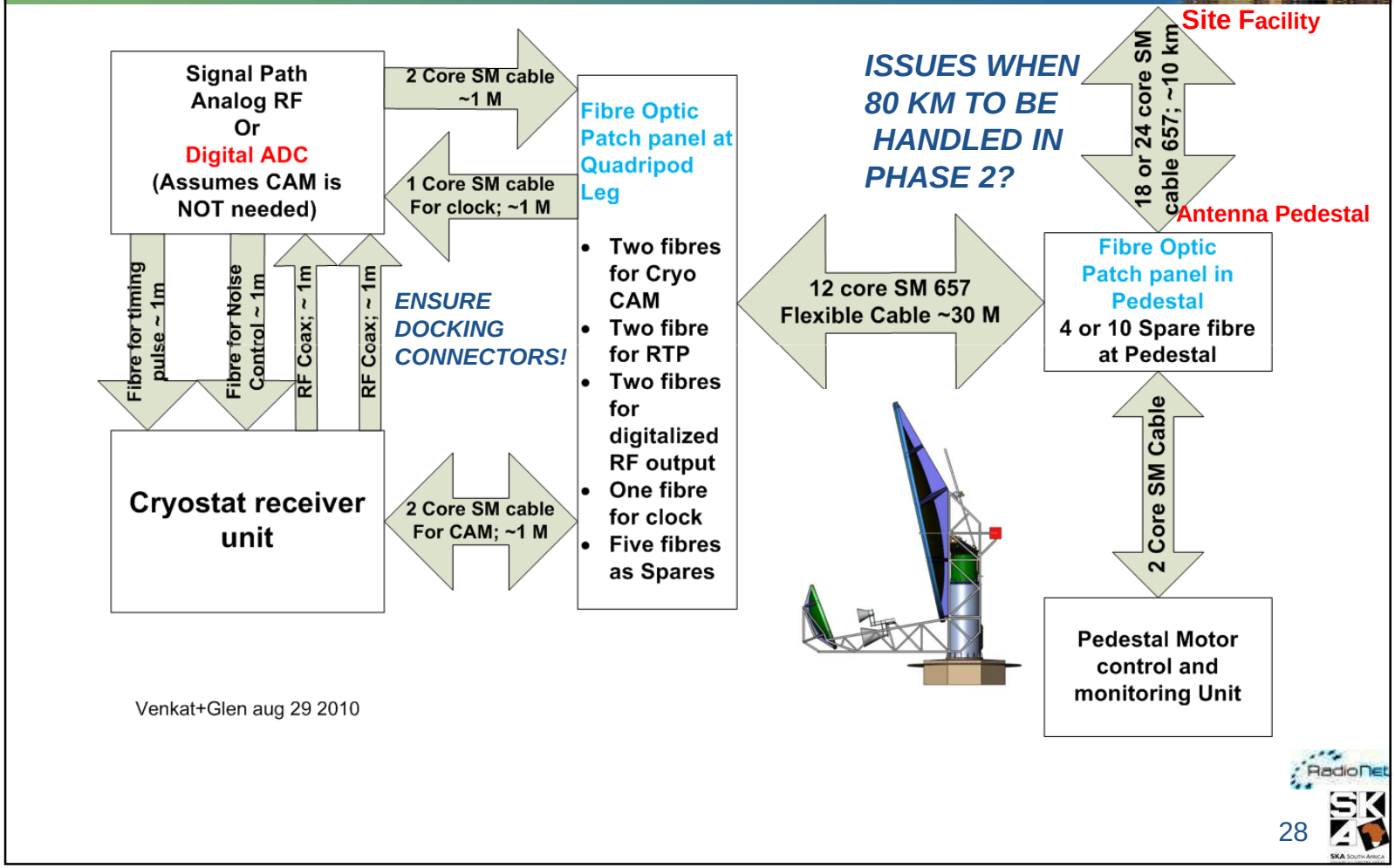


Issues to address

- *Unified Solution valid for all phases*
- Terminal devices – temperature stabilisation
- OF Cable Phase-Temperature Coefficient
- OF Cable Performance Stability with bending, torsion and environment
- Ruggedised Connectors suitable for use at focus of antenna
- Ease of maintainability – Any fault needs a cherry picker to attend!
- Quick turn-around maintenance as a design criterion



The meerKAT Optonics: Cable Network



The meerKAT Optonics: Riser Cable

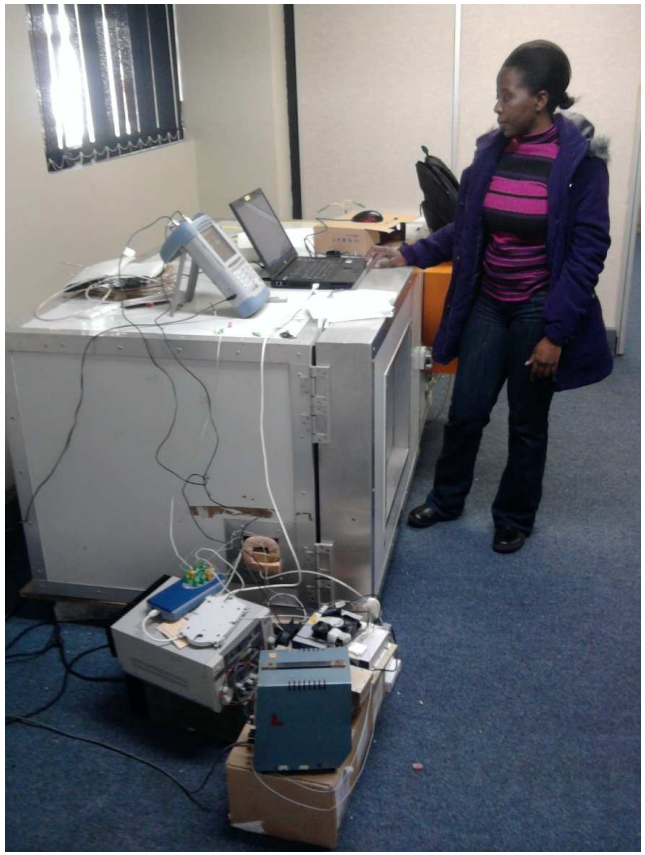
- **The research on a suitable Riser Fibre Cable for use from Pedestal to Focus at each antenna is under advanced stage of development together with CBi Electric, South Africa**

- **It uses Aramid polyurethane sheath for 6 SM fibre of 652 or 657 type in a loose tube construction of 2.2 mm dia**

- **The cable has successfully undergone torsion, drip, tensile strength, flexure, tube kink, cable kink, repeated bending, mandrel bending, impact, crush test (plates), temperature cycling and UV accelerated tests to the relevant TELKOM or IEC 794 specifications.**

- **CBi suggests that we use 657 cable for BOTH Riser as well as buried cable needs as**
  - **Corning has recently made the price of both cables same and**
  - **657 is likely to be the Industry Standard for SM applications in a few years.**

The meerKAT Optonics: Riser Cable

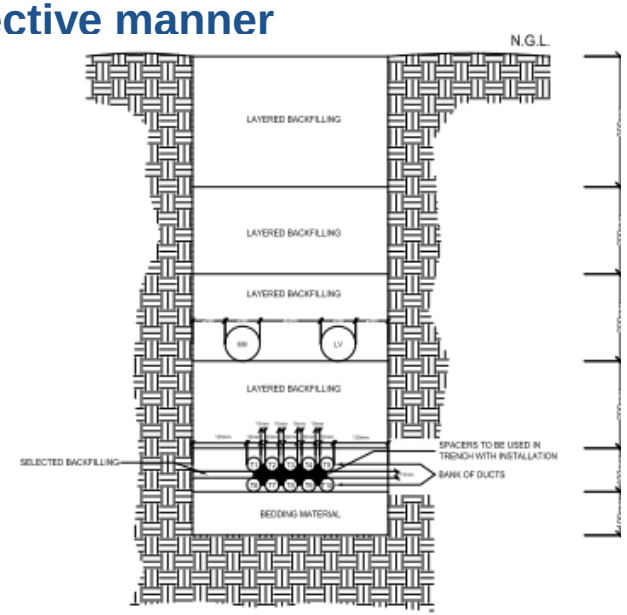


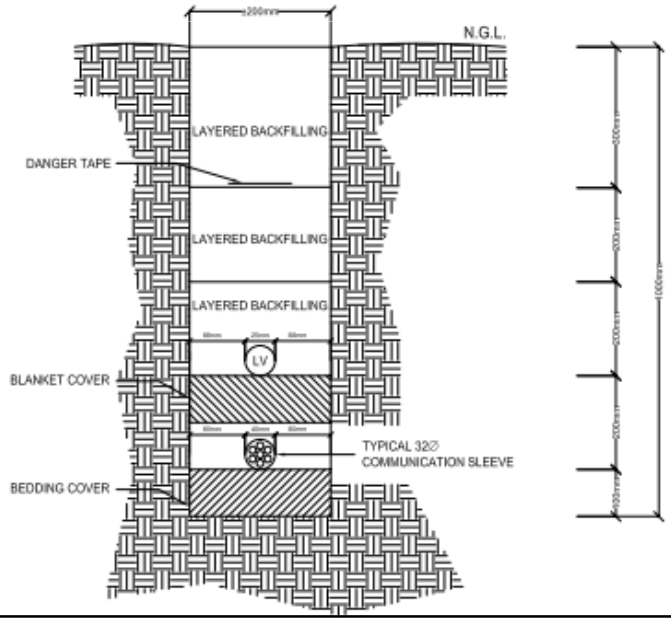
- The phase-temperature-coefficient of a sample cable using 652 and 657 fibre has been measured (PRELIMINARY) as around 6 ppm per deg C.
- e-VLA has quoted a figure for a Corning fibre of 2 ppm/ deg C in memos #32 and #44.
- Need to understand what is the best figure possible to take a decision on round trip phase investment
- Further in-house RF tests to estimate behaviour with mechanical and environmental factors are planned at the facilities of Tellumat.
- The cable is planned to be laid between the focus and pedestal of the last three KAT-7 antennas for rigorous field evaluation

The meerKAT Optonics: Buried Cable

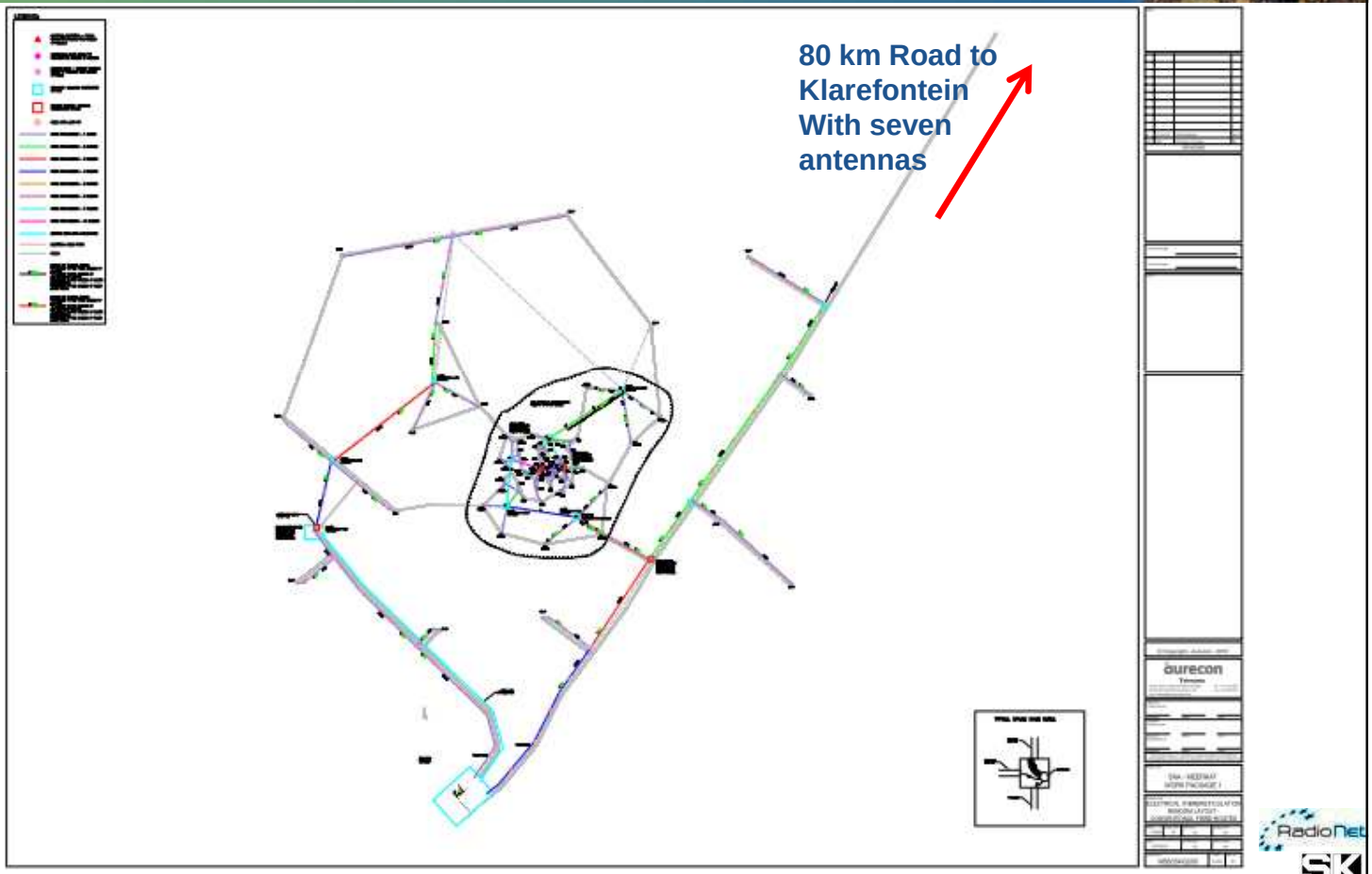
- **The concept studies on the Buried Optical Fibre Cable to link Pedestal of each antenna with Site Facility is at an advanced stage of visualisation, together with Aurecon and SIA Solutions, South Africa**

- **The exercise takes advantage of the need for other infrastructure requirements of meerKAT like power distribution and roads in a cost-effective manner**





The meerKAT Optonics: Buried Cable



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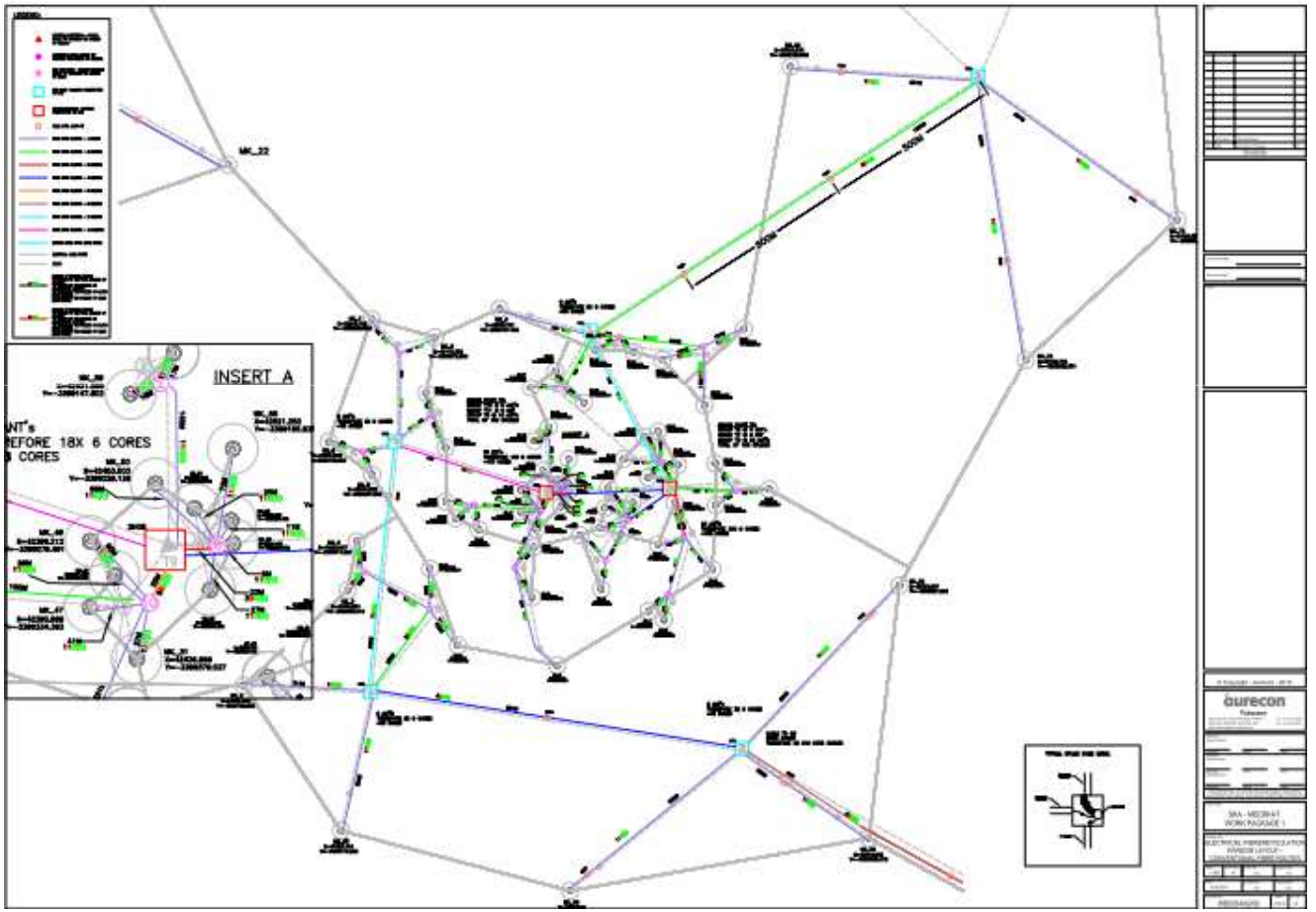
The meerKAT Optonics: Buried Cable



The meerKAT Optonics: Connectors

- **The investigation of suitable ruggedised connectors for use at focus of each antenna is in progress, together with Tellumat, South Africa**

- **FC-APC or E-2000 APC connectors essential for analog RF. Threaded connectors with Guide mechanism to ensure proper AND REPEATABLE alignment of the angle-polished end surfaces while maintaining the air-gap is essential from RELIABLE performance point of view.**

- **Would PC connectors be adequate for the digitised astronomical signals?**

- **Would FIBRE+POWER connectors (and cables) be an advantage?**

The meerKAT Optonics: Connectors

- **Need to ensure performance ruggedness for conditions like RFI leakage, resonances in antenna and other vibration, temperature excursions, wind, rain, dust, sun's UV and heat, pecking by birds, bird-nests…….**

- **Following have been identified as prospective connectors:**
  - **Huber-Suhner's ODC range of IP-67 grade APC connectors**
  - **M38999 series MIL grade connectors from different vendors like Aldo-Souriau, Huber-Suhner, ITT etc**
  - **ELIO Hermatic Bulkhead Feed-Thro Connectors in case needed for use within cryo**

- **Rigorous tests are planned at the Test facilities of Tellumat for in-house qualification and verification of performance (not for birds!)**

The meerKAT Optonics: Terminal Devices

- **Preliminary investigation of suitable 15 GHz Optical Transmitter and Receiver for an analog link has been completed and is currently in the back-burner. Adequate ground work has been done with Photonics, Miteq and Foxcom.**

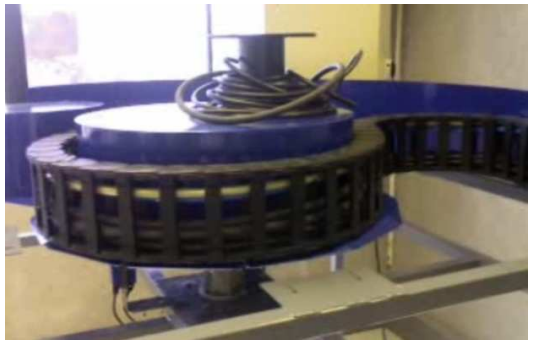
- **In-house (in-country?) development of the terminal Tx-Rx hardware is under consideration, preferably as a collaborative effort for mutual benefit with leading Organisations, especially for meeting the needs of single tone round-trip-phase and clock distribution functionalities**

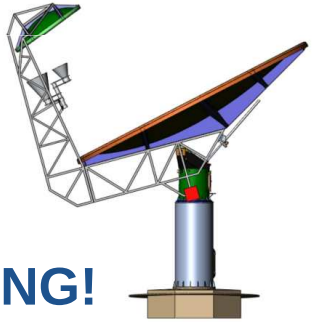
- **Discussions with e-VLA group on round-trip phase and clock distribution concepts for adapting to meerKAT is in preliminary stages**

- **Thermal solutions involving Stabilisation Above Maximum Ambient is under investigation**

CONCLUSIONS

How to conclude on something which is just starting with NEW GOALPOSTS?





THANX FOR YOUR PATIENT LISTENING!

QUESTIONS?