NRF / SKA SA Dish Concept: Risk and Risk Mitigation

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NRF / SKA SA
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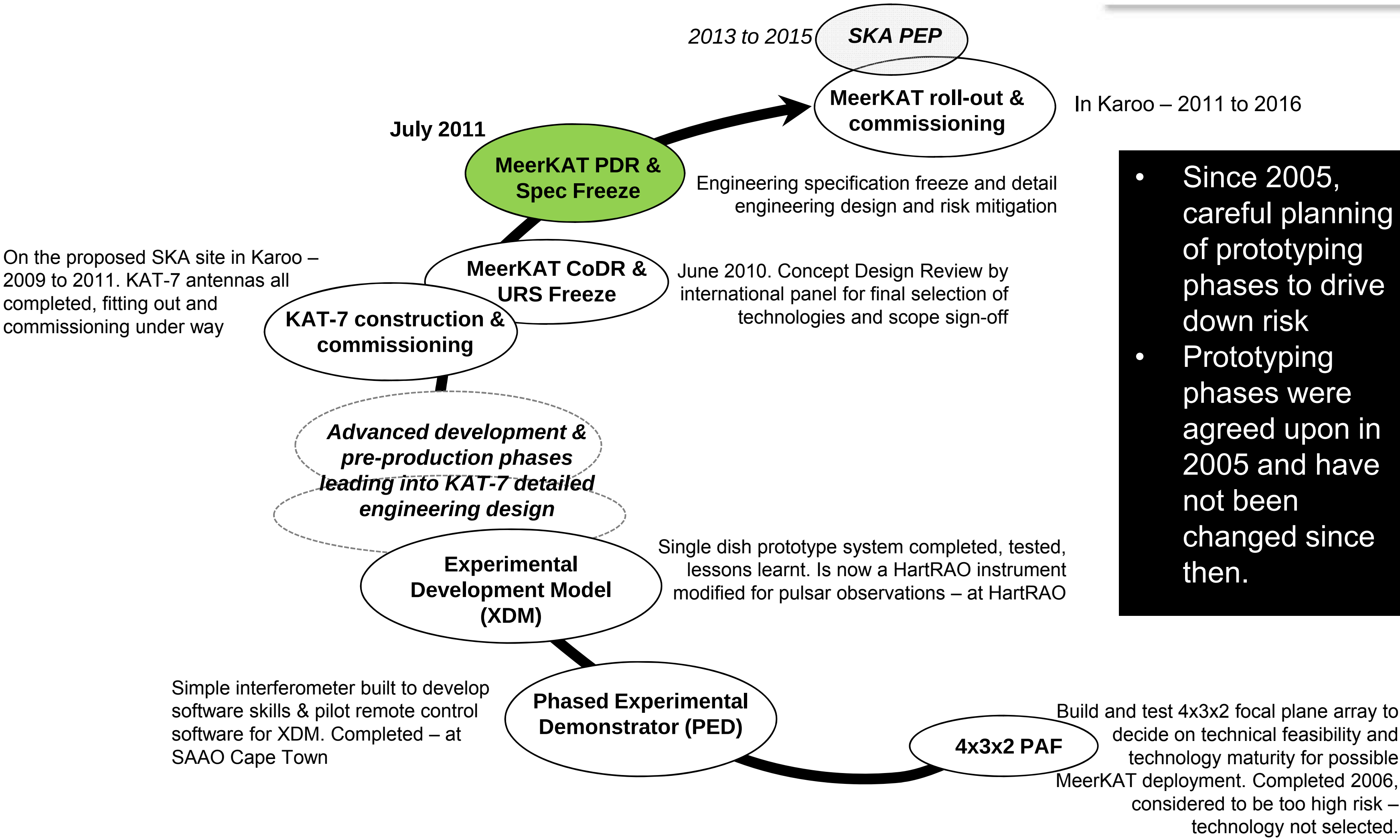
Penticton

Overview: Risk-driven phased development strategy



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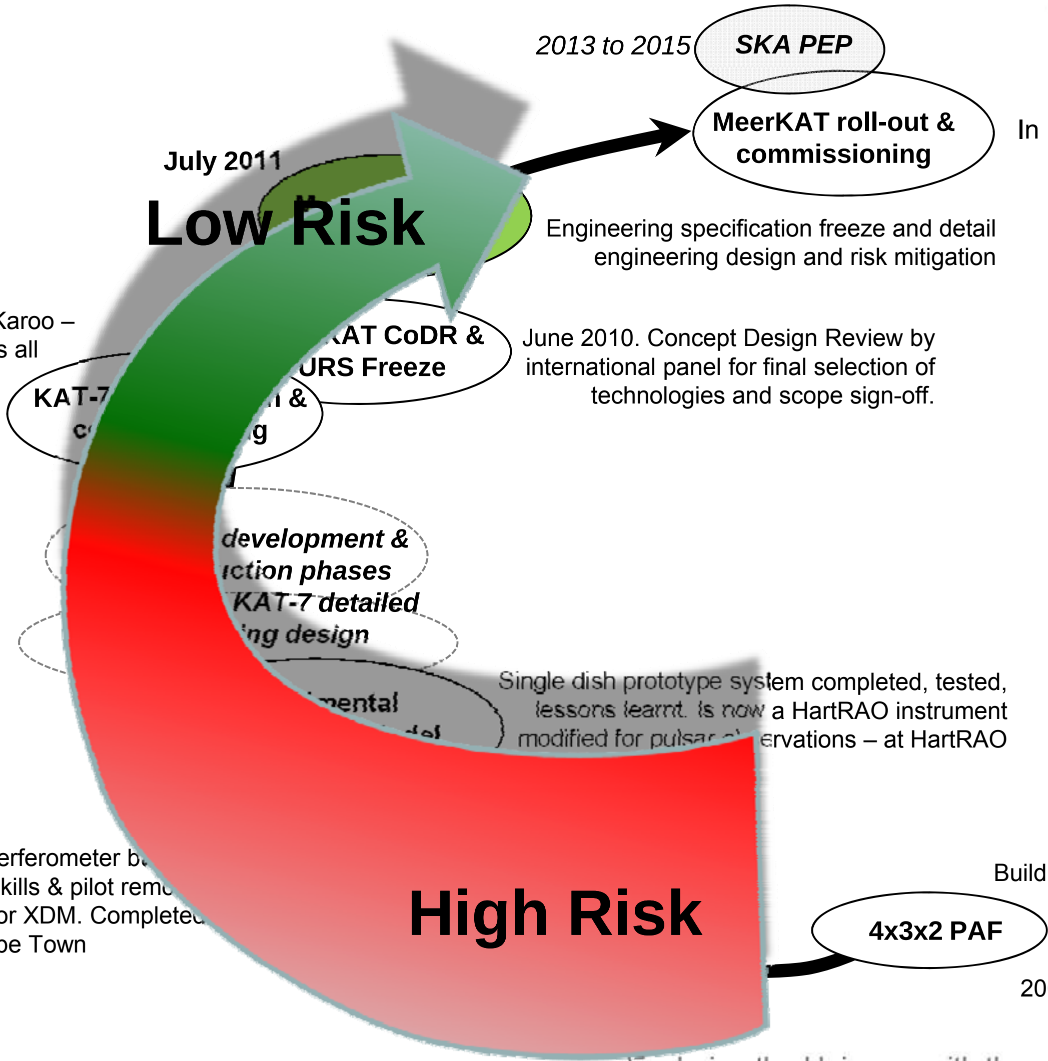
- Prototyping phases were agreed upon in 2005 and have not been changed since then.

Overview: Risk-driven phased development strategy



In Karoo – 2011 to 2016

Engineering specification freeze and detail engineering design and risk mitigation

On the proposed SKA site in Karoo – 2009 to 2011. KAT-7 antennas all completed, fitting out and commissioning under way

June 2010. Concept Design Review by international panel for final selection of technologies and scope sign-off.

Single dish prototype system completed, tested, lessons learnt. Is now a HartRAO instrument modified for pulsar observations – at HartRAO

Simple interferometer b... software skills & pilot remo... software for XDM. Completed... SAAO Cape Town

Build and test 4x3x2 focal plane array to decide on technical feasibility and technology maturity for possible MeerKAT deployment . Completed 2006, considered to be too high risk – technology not selected.

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SKA SA Risk Register

- **Risks Register** forms an integral part of the management of risk.
- A risk is defined as "*an uncertain event or condition that (should it occur) would negatively impact cost, schedule or performance.*"
- A risk is described by the title of the event or condition, its probability as well as the consequences resulting from its occurrence (impact).
  - Risk identification number, responsible person to address risk, mitigation action and risk retirement date agreed
- Risk management is concerned with systematically identifying, analysing and treating project related risks.
- The Risk Exposure is calculated on the basis of an estimated cost implication and predicted schedule impact, should the risk realise.

Risk Exposure (RE) = Probability Score x (Cost Impact Score + Schedule Impact Score)

Risk management

Risk ID

Risk Title

Risk Type *(major, track or noted)*

Probability Score *(1,2,3 or 4)*

Cost Impact Score *(1,4,6 or 8)*

Schedule Impact Score

Risk exposure (calculated)

Responsibility, mitigation action, retirement date

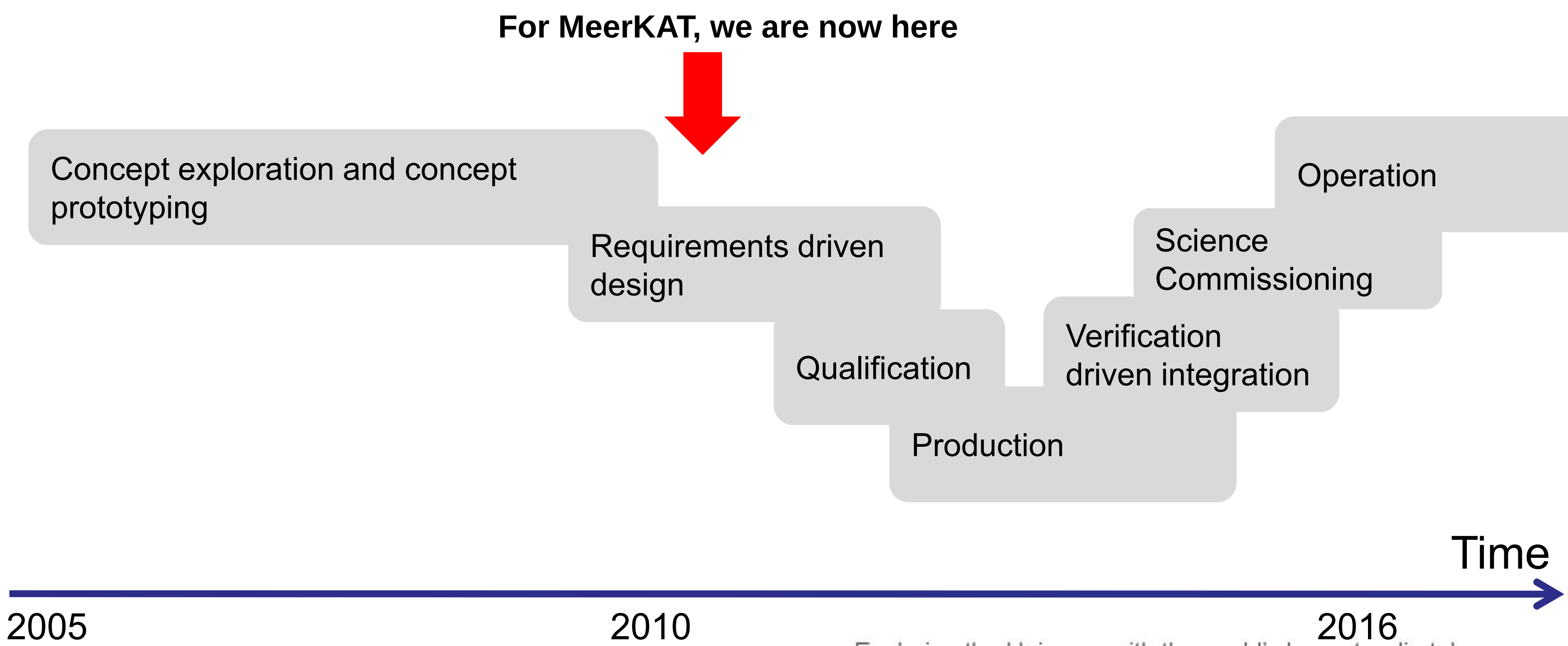
Antenna and Feed Risks Register - July 2011

Risk ID	Risk Title	Risk Type *(major, track or noted)*	Probability Score	Cost Impact Score	Schedule Impact Score	Total Score	Risk Exposure (Calculated) *(very high, high, medium, low)*	Responsibility	Mitigation Action	Target Risk Retirement Date
Antenna										
ANT01	There is a risk that the support structure of the secondary reflector and the feed will not be stiff enough caused by geometric constraints, resulting in the specifications for pointing accuracy and focal point deflection not be met in the wind loadcase. Note that the present concept design lowest frequency is 1.5Hz. (This mode is left/right of the support structure.) Ideally, the value for this is >3Hz (which means x4 increase in stiffness.)	MAJOR	4	8	1	36	HIGH	WE	Adapt design of support structure for lateral stiffness. FEM the loadcase "wind 60deg, pointing at 15 deg".	Design Study prior to contract award. Dec 2011
ANT02	There is a risk that the forces are large in case of the survival load case for wind and rain cuased by a stow position with the main reflector at an angle, resulting in too large forces on the ballscrew and large forces on the foundations.	TRACK	2	6	4	20	MEDIUM		Analyse and Design for the optimal stow position given geometry, wind, water.	Design Study prior to contract award. Dec 2011
ANT03	There is a risk that the concept design is inadequate for some load case (for instance the loadcase survival at 160km/h and rain) caused by the fact that this is a concept study only and a FEM done for these cases based on calculations rather than a full CFD, resulting in parts that have to be stronger/stiffer and cost more than the concept design.	TRACK	2	4	4	16	MEDIUM		Complete the detail desing and analysis and adapt the design accordingly.	Design Study prior to contract award.
ANT04	There is a risk that the duty cycle on the ball screw is too high for the required life time, caused by the load cases and potential higher (60km/h) stow wind speed, resulting in a larger ball screw to be selected.	TRACK	2	4	4	16	MEDIUM		1. If, during the detail design, the risk materialises, select a larger ball screw. 2. Instrument ball-screw on KAT7 to determine the cyclical loading and compare actual forces with calculated forces. 3. Leadscrew test jig will likely be built to test leadscrew for fatique life and loading.	1. CDR 2. Design Study prior to contract award. Dec 2011 3. CDR
ANT05	There is a risk that the KAT7 motor power is too small for the Offset antenna, caused by the inertia of the Offset antenna being double the KAT7 inertia, resulting in higher power consumption, larger servo drivers and larger motors.	TRACK	3	6	4	30	MEDIUM		If, during the detail design, the risk materialises, select larger motors. Note the possible effect on the power budget.	CDR
ANT06	There is a risk that the cyclic error in the azimuth control loop caused by the pinion-ring gear meshing as experienced in certain operational conditions on KAT7 will be too large for the Offset requirements, resulting in the pointing specification being failed.	MAJOR	3	8	6	42	HIGH		Simulation of control loop. Design optimisation of gear profile.	CDR
ANT07	There is a risk that meerKAT contract will be placed only in Q2 2011, and not in Q4 2010 latest, caused byadmin delays, and that the total meerKAT delivery schedule will remain constant, resulting in a pressure on the development, mould manufacturing schedule and concurrent building of the first antennas - this might result in retrofits required on the first antennas that has been built priot to qaulification on the first antenna being completed.	MAJOR	4	4	6	40	HIGH		1. Ensure that development and industrialisation sequence of events is aimed at minimising risk (and optimising production performance/cost). 2. Proceed with mould concept design before antenna contract placed. 3. Do as much conceptual work as early as possible.	Design Study prior to contract award. Dec 2011

Risk-driven engineering phases

Concept exploration phase | Product engineering phase | Operational phase

For each system we built, we went through all engineering phases.



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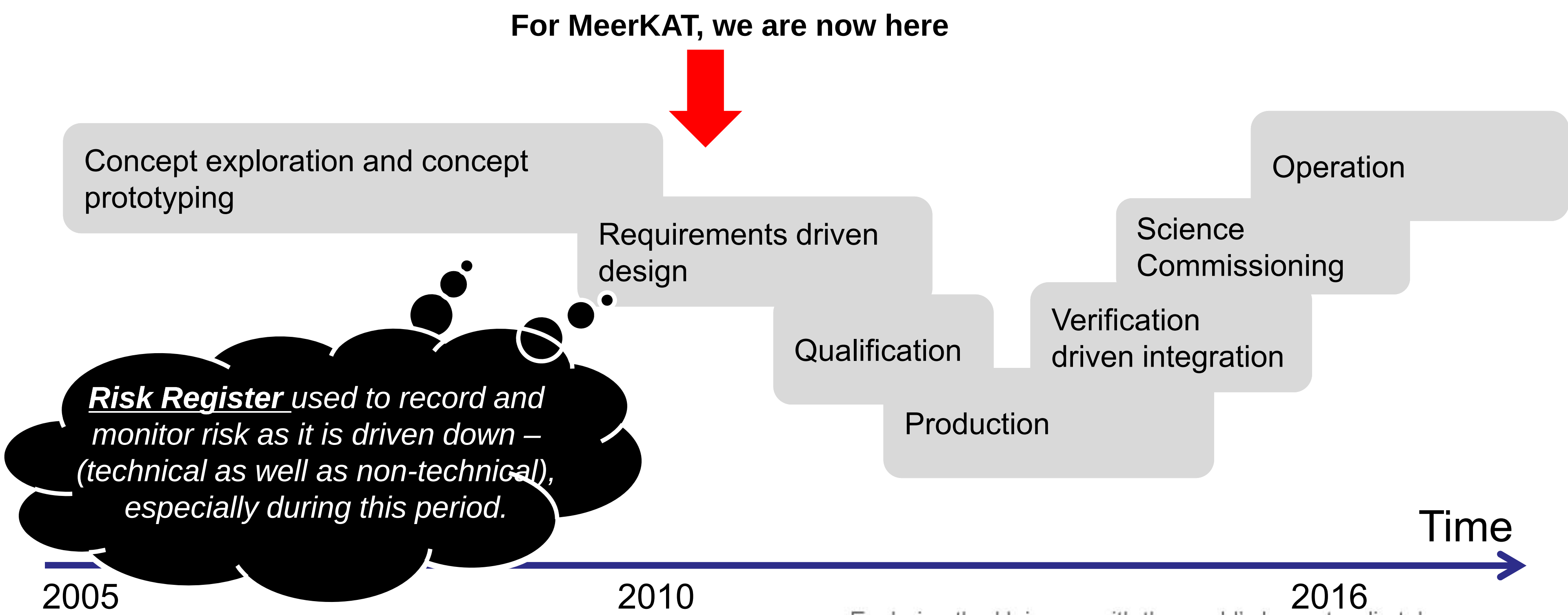
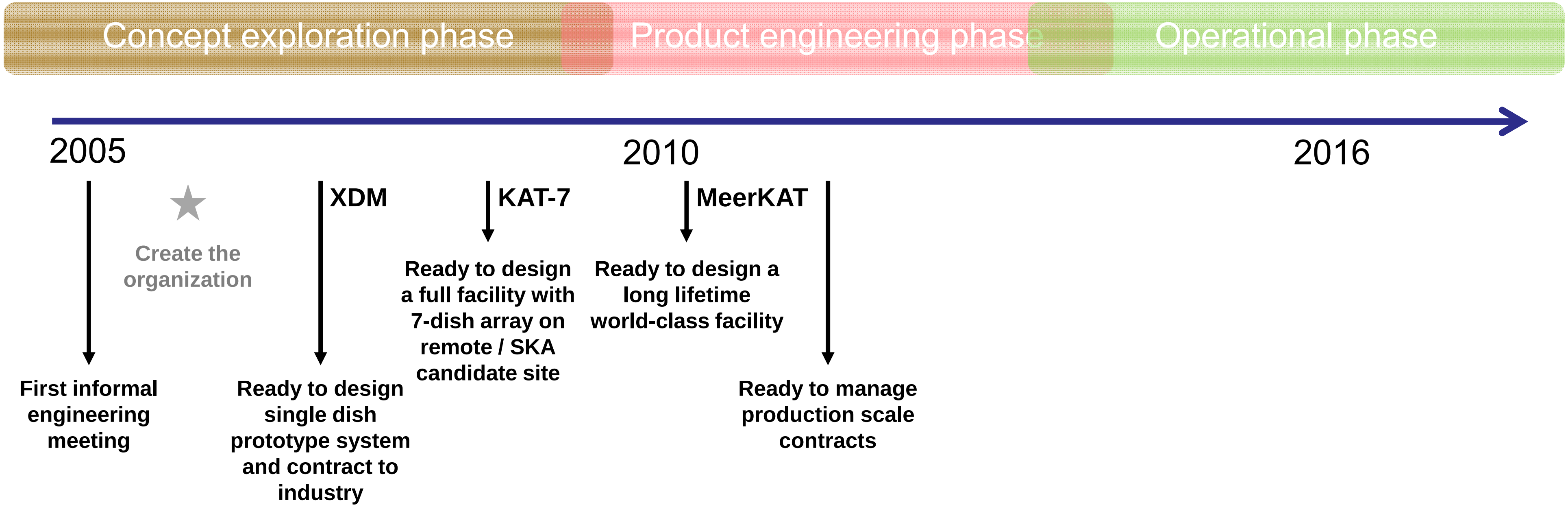


Engineering phases
Organisational

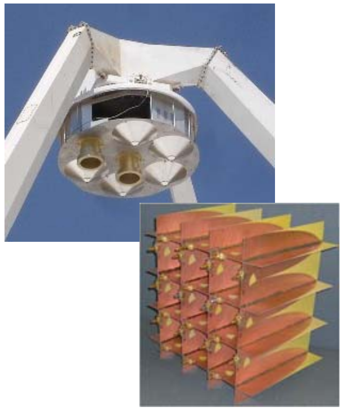


Engineering phases
Driven by URS

Concept exploration phase | Product engineering phase | Operational phase

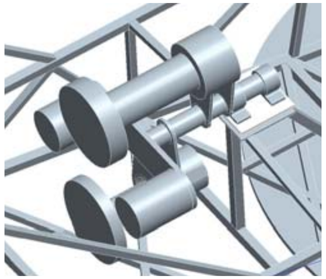
2005 — 2010 — 2016

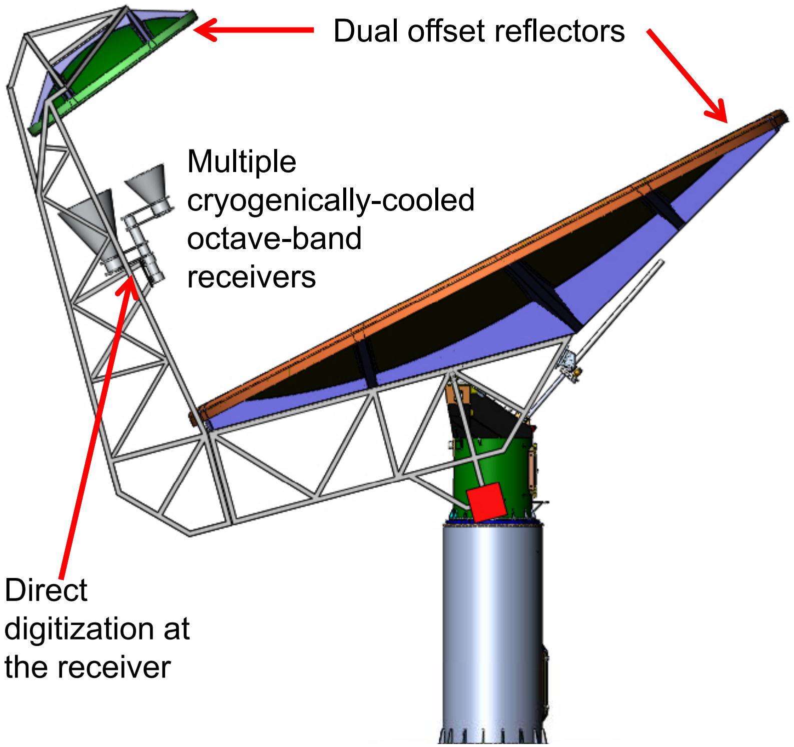
XDM
Survey speed
(field of view)
Cluster feed



KAT-7
Sensitivity
Single-pixel cryogenically cooled feed

MeerKAT
Imaging Dynamic Range
Feed indexer with cryogenically cooled feeds





MeerKAT CoDR outcome - June 2010

Our underlying philosophy:
“Freeze MeerKAT concept as late as possible to align with SKA direction and to ensure maximum science.”

Engineering phases
Technologies

Concept exploration phase | Product engineering phase | Operational phase

2005 — 2010 — 2016

★ Concept

★ Production starts

Our underlying philosophy:
"Freeze MeerKAT concept as late as possible to align with SKA direction and to ensure maximum science."

- **Free to choose viable technologies**
- **Prototype most promising technologies**
- **Technology must be proven through rigorous qualification**
- **Benefit from emerging technologies (e.g. computing) "Buy as late as possible"**
- **Phases 2 & 3 to remain world-class**

MeerKAT phased deployment

- 2013:1 antennas deployed (qualification model)
- 2014:16
- 2015:40
- 2016: 64 antennas, feed indexer fitted, one feed only
- 2018: 64 antennas, each with 3 feeds & receiver configuration deployed

Risk mitigation for MeerKAT
Antenna

- Composites Materials Qualification Programme
  - Geometric stability of the reflective surface
  - Mechanical integrity of the reflective surface
  - Resin / paint system dielectric loss factor
  - Resin film thickness in front of mesh
- Antenna concept analyses
  - Mould design, manufacturing processes and work flow
  - Asymmetric curing distortions
  - Carbon fibre costs (significant work already done wrt structural analyses for carbon fibre instead of glass fibre)
  - Offset antenna wind loads investigation
  - Offset antenna alignment strategy
- Optics optimization

Layer no	Material	Thickness [mm]
1	Paint (Goldstone 500HR6)	0.1
2	Paint undercoat	0.05
3	Aluminium mesh	0.6
4	E-glass polyester laminate	2.3
5	PVC core 80kg/m^3	10
6	E-glass polyester laminate	2.8
7	Paint	0.2

Table 25. Proposed antenna dish lay-up.

KAT-7 resin = Herex C70-75

Risk mitigation for MeerKAT

Antenna: extract of "major" risks from risk register

Risk Title	Mitigation Action	Target Risk Retirement Date
The support structure of the secondary reflector and the feed will not be stiff enough (caused by geometric constraints), resulting in the specifications for pointing accuracy and focal point deflection not be met in the wind load-case. Note that the present concept design lowest frequency is 1.5Hz.	Adapt design of support structure for lateral stiffness. FEM the load-case "wind 60deg, pointing at 15 deg".	Design Study prior to contract award. Dec 2011
The cyclic error in the azimuth control loop caused by the pinion-ring gear meshing as experienced in certain operational conditions on KAT7 will be too large for the Offset requirements, resulting in not meeting the pointing specification.	Simulation of control loop. Design optimisation of gear profile.	CDR
Schedule risk – Any administrative delays (meerKAT contract placed only in Q2 2011, and not in Q4 2010), **with** the total meerKAT delivery schedule remaining constant, will result in pressure on the development, mould manufacturing schedule and concurrent building of the first antennas - this might result in retrofits required on the first antennas that has been built prior to qualification on the first antenna being completed.	1. Ensure that development and industrialisation sequence of events is aimed at minimising risk (and optimising production performance/cost). 2. Proceed with mould concept design before antenna contract placed. 3. Do as much conceptual work as early as possible.	Design Study prior to contract award. Dec 2011
Pointing accuracy requirement cannot be attained in a cost effective way for all load cases, due to thermal expansion and wind effects, resulting in various compensating measures such as the following: 1. The pointing model will have to include temperature effects, caused by the accuracy requirements, resulting in thermo-sensors to be fitted to various points on the antenna and the development of a pointing model based on these inputs. 2. Heat shields on the back of the main reflector. 3. Recording of servo error & wind RF data to calculate a confidence value for measurements . 4. Relaxation of specifications for certain load cases.	1. Analyse the error. 2. Design and model the effect of temperature-based pointing compensation and test on KAT7 if deemed necessary. 3. Define operational profiles with tightest pointing requirements only required under optimal conditions. 4. Test & optimise on the first antenna and on KAT7 where possible. 5. Investigate feasibility to log wind/temperature/pointing error in RF data files to assign confidence to RF recordings 5. Provision has been made for thermal sensors on KAT7 so thermal corrections can be implemented and tested on KAT7.	Qualification of first antenna

Risk mitigation for MeerKAT

"Major risks": Feed and cryogenics

- Sensitivity drive – Resulted in reduced-bandwidth receiver
  - No mitigation possible for MeerKAT phase 1 (due to timescales)
  - Emerging (wideband) antenna art will be considered for phase 2
- Cryogenics – Risk of immature components failing too soon
  - Will be mitigated by HASS testing during development
  - Will however be a significant component of operational maintenance
- Optics – Risk of inbreeding between geometry & KAT-7 horn art
  - Will be mitigated by Post-PDR future-proofing study
- Unknown (Dynamic Range) unknowns – Schedule risk
  - Mitigation by diligent engineering (stability has been achieved before)

*HASS = **H**ighly **A**ccellerated **S**tress **S**creening*

Risks Mitigation for MeerKAT

“Major risks”: Digitizer

- **Radio Frequency Interference (RFI)**
  - Just shielding the digital bits by placing them in a box is not good enough. All CAM/SPT data connections are digital Ethernet over optical fibre (OK) but RF will leak out through power connections as well as the input leads for the ADC.
  - Areas under study
    - Careful design for RFI mitigation
    - Strategic placement of RF components
    - RFI-aware digital PCB layout, individual shielding of various components and power supply decoupling are some of the areas under study. We have some experience with this already - ROACH-1 in its RFI-aware enclosure has proven to be very quiet with the largest emission coming from an on-chip clock processor attesting to the good PCB layout principals employed.
- **High speed ADCs**
  - Digitising L-band is very easy with current technologies (~4Gsa/s).
  - However, the technology for sampling X-band (~30Gsa/s) is not yet mature.
    - Various companies are almost there though and we believe that these devices will be commercially available well before MeerKAT needs them. We are following the developments of this closely. Many other observatories have similar needs (CARMA, SMA etc) and are currently evaluating engineering samples of high speed ADCs from multiple vendors. We are in regular contact with these collaborators and will learn from their experiences. In parallel, we have been investigating the use of interleaved ADCs to cover higher bandwidths. It is still unclear if the signal fidelity of such interleaved systems will be sufficient for sensitive radio astronomy use.

Risks Mitigation for MeerKAT

"Major risks": Digitizer (2)

- **Heat dissipation/cooling**
  - We wish to avoid active cooling systems which are maintenance-heavy.
  - Back-of-the-envelope calculations suggest that the digitiser can be cooled passively (ie no fans, water, gasses or other moving mechanics) with heat-pipes to fins on the outer enclosure. This would greatly improve reliability, reduce power consumption and simplify the design. But this box will be exposed to the elements with highly-varying ambient temperatures and the analogue RF chain components (some of which are housed in the digitiser box) must be maintained at a constant temperature in order to ensure gain and phase stability. MeerKAT requirements will need these temperatures to vary by less than a degree over a 10 minute period. So we are considering heating certain components under closed-loop control. This will increase MTBF of these components and so this needs to be implemented carefully.
- **Sampling clock distribution**
  - Closed-loop control (as used by the EVLA) should solve this problem. But while well-understood, the MeerKAT team has no experience with such systems.
  - Two options are currently under consideration: distribute the sampling clock directly or else distribute a reference frequency and use a phase-locked-loop (PLL) scheme whereby each ADC unit generates its own sampling frequency locked to the central reference clock. Issues of system synchronisation are solved already.