Mid Key Parameters

• **Modes:**
  - Imaging (continuum and spectral)
  - Pulsar Search
  - Pulsar Timing
  - Flow through
  - Dynamic Spectrum
  - Transient Search
  - Very-Long Baseline Interferometry (VLBI)

• High time & spatial resolution
• Flexible Scheduling
• Commensal Observing
• 95% Operational Availability
A key challenge – RFI (external & self-induced)

Example of analysis: Attenuation of emitted RFI in Central Processing Facility
A key challenge – RFI

Example of analysis: Attenuation of emitted RFI in Central Processing Facility
SKA – Mid Pre-cursors on Mid site

KAT-7

MeerKAT

HERA

Exploring the Universe with the world’s largest radio telescope
Use MeerKAT antennas and infrastructure

Exploring the Universe with the world's largest radio telescope
Mid Telescope Implementation
SKA1-MID Configuration

- 133 SKA 15m dishes
- 64 MeerKAT 13.5m dishes
- Maximum baseline 150 km
- 3 logarithmic spiral arms
- Frequency range: 350 MHz to 15.4 GHz

The Square Kilometre Array Observatory
SKA1-MID Configuration

- 133 SKA 15m dishes
- 64 MeerKAT 13.5m dishes
- Maximum baseline 150 km
- 3 logarithmic spiral arms
- Frequency range: 350 MHz to 15.4 GHz
Infrastructure

- Water
- Roads
- Power
- Fibre
- Buildings
  - CPF (KAPB)
  - EOC
  - SPC
- Cooling
- Dish Foundations
Dish Foundations

- Challenging stiffness to achieve pointing spec
- Prototype foundation
- Stiffness tests done
- Piling depends on soil per antenna
SKA1 Mid Antenna

Antenna Features

- Frequency: 350MHz – 20GHz +
- 15 metre offset Gregorian optics
- Sub-reflector: 5 m, with skirt
- Tracking speed: 30 times sidereal rate @ 10arcsec accuracy
- Slewing Speed:
  - 1deg/sec elevation
  - 3deg/sec Azimuth
- Indexing speed: Less than 30 sec
Antenna Pedestal

Pedestal Features

- High stiffness
- Azimuth bearing & encoder
- Houses control & network equipment
- EMI Shielded Compartment:
  - 145 dB (50 MHz - 13.8 GHz)
  - 95 dB (13.8 - 20GHz)
- Tilt and temperature sensors to improve pointing
# Antenna Performance

## Sensitivity per Band estimates

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency (GHz)</th>
<th>BW (MHz)</th>
<th>Sensitivity Requirement (m²/K)</th>
<th>Design (m²/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Array (L1)</td>
<td>Dish (L2)</td>
</tr>
<tr>
<td>1</td>
<td>0.35 – 0.650</td>
<td>700</td>
<td>272 – 545</td>
<td>545</td>
</tr>
<tr>
<td>2</td>
<td>0.65 – 1.050</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.95 – 1.760</td>
<td>808</td>
<td>916</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.65 – 3.050</td>
<td>1403</td>
<td>916</td>
<td></td>
</tr>
<tr>
<td>5a</td>
<td>1.65 – 3.050</td>
<td>1403</td>
<td>916</td>
<td></td>
</tr>
<tr>
<td>5b</td>
<td>2.80 – 5.180</td>
<td>2380</td>
<td>833</td>
<td></td>
</tr>
<tr>
<td>5a</td>
<td>4.60 – 8.500</td>
<td>3900</td>
<td>1110</td>
<td></td>
</tr>
<tr>
<td>5b</td>
<td>8.30 – 15.40</td>
<td>7000</td>
<td>805</td>
<td></td>
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</tbody>
</table>

## Pointing performance estimates

<table>
<thead>
<tr>
<th></th>
<th>RMS error (arcsec)</th>
<th>RMS error (arcsec)</th>
<th>RMS error (arcsec)</th>
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</thead>
<tbody>
<tr>
<td><strong>Blind Pointing Error</strong></td>
<td>Requirement</td>
<td>9</td>
<td>18</td>
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<td></td>
<td>Design</td>
<td>5.5</td>
<td>11</td>
</tr>
<tr>
<td><strong>Relative Pointing Error</strong></td>
<td>Requirement</td>
<td>1.3</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>1.2</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>Tracking Stability</strong></td>
<td>Requirement</td>
<td>2.3</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>1.5</td>
<td>4.4</td>
</tr>
</tbody>
</table>
SKA1-MID Feed Indexer

- Supports 3 feed packages
- Removable sun shields for sunlight and rain protection
- Supports 2 digitisers, vacuum pump, power and fibre

- Rotation: 203 deg (feed packages ~100 deg apart)
- Overall center of mass close to the axis of rotation
Band 1 Single Pixel Feed

- 350MHz – 1050MHz; 3:1 bandwidth
- Dual Polarisation
- Quad Ridged Feed Horn
- Room temperature LNAs (Low Noise Factory)
- LNAs embedded in fins – minimise losses

Qualification tests on MeerKAT
Band 2 Single Pixel Feed

- 950MHz – 1760MHz; 1.85:1 bandwidth
- Dual Polarization
- Crossed dipole-based Ortho Mode Transducer (OMT)
- LNAs cooled to 20K; OMT cooled to 70K
- Coolstar 2/9 cryocooler
- Feed package based on MeerKAT design
Band 345 Single Pixel Feed

- Modular Cryostat, dual polarisation
- Supports Bands 3, 4, 5a, 5b and 5c
  - 5c not defined in detail
- Band 5a (4.6GHz – 8.5Hz) and Band 5b (8.3GHz – 15.4GHz) fitted initially
- Band 5a/5b feeds cooled to 70K; LNAs at 20K
- Coolstar 6/30 cryo-cooler
- Band 5a – quad-ridged OMT; Band 5b turnstile OMT

<table>
<thead>
<tr>
<th>Band</th>
<th>Freq. [GHz]</th>
<th>BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 3</td>
<td>1.65 – 3.05</td>
<td>1.84</td>
</tr>
<tr>
<td>Band 4</td>
<td>2.80 – 5.18</td>
<td>1.85</td>
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<tr>
<td>Band 5a</td>
<td>4.6 – 8.5</td>
<td>1.84</td>
</tr>
<tr>
<td>Band 5b</td>
<td>8.3 – 15.4</td>
<td>1.84</td>
</tr>
</tbody>
</table>

The Square Kilometre Array Observatory
SKA1-MID SPF Receiver (Digitisation)

- RF samplers located on the Feed Indexer
- Packetiser, DSP and C & M located in RFI enclosure in the Dish Pedestal (TALON)
- Separate Band 123 and 345 Digitisers

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency (GHz)</th>
<th>RF BW (MHz)</th>
<th>Sampling Rate (GSps)</th>
<th>Nyquist Zone</th>
<th>ADC Sampling Bit Depth</th>
<th>Transport Sampling Rate (GSps)</th>
<th>Transport Bit Depth</th>
<th>Transport Data Rate (Gbps)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.35 – 1.050</td>
<td>700</td>
<td>3.96</td>
<td>1</td>
<td>8</td>
<td>3.96*</td>
<td>12</td>
<td>95.04</td>
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<tr>
<td>2</td>
<td>0.95 – 1.760</td>
<td>808</td>
<td>3.96</td>
<td>1</td>
<td>8</td>
<td>3.96*</td>
<td>12</td>
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<tr>
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<td>1.65 – 3.050</td>
<td>1403</td>
<td>3.168</td>
<td>2</td>
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<td>3.168*</td>
<td>12</td>
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<td>4</td>
<td>2.80 – 5.180</td>
<td>2380</td>
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<td>5.94*</td>
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<tr>
<td>5a</td>
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<td>8.30 – 15.40</td>
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<td>15.84</td>
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<td>3</td>
<td>2 x 5.94*</td>
<td>4</td>
<td>95.04</td>
</tr>
</tbody>
</table>

*Offsets are added to these frequencies to reduce correlated noise
Signal and processing chain

- **Antenna**
- **Feed Hardware**
- **RF Electronics**
- **RF Gain**
- **Digitisation**
- **Sub-Band Filtering**
- **Long-haul Links**
- **Fibre Opto-electronics Optical Amps**

- **Dishes & Receivers**
  - Precision Dynamic Structures, Motion Control, Optics
  - Feeds, Cyrogencs* Enclosures
  - LNA & Amplifier
  - Amplification & Filtering
  - Sample Clock & Time Stamp Generation
  - Digital Filter

- **Data Transport**
  - Ingest Switch
  - Transient Data
  - Science Data Processing
  - Science Data Archive & Distribution
  - VLBI Terminal Equipment/Interface

- **Science Processing Facility**
  - VLBI Data
  - Transient Data
  - Visibility Data
  - VLBI Data

- **Central Processing Facility**
  - VLBI Data
  - Transient Data
  - Visibility Data
  - VLBI Data

- **Observatory Clock System**
- **Channeliser, Beamformer & Correlator**
- **Pulsar Search**
- **Pulsar Timing**
- **High-speed Digital Hardware**

- **Advanced Time Keeping & Distribution**
- **Operation, Control and Monitoring Systems**
- **Telescope Manager**

- **Candidates & Timing Data**
- **HVLBI**

- **VLBI Data**
  - Transient Data
  - Visibility Data

- **Advanced Time Keeping & Distribution**

- **Data Transport**

- **Front-end Data Routing**
  - Specialised Digital Hardware
  - Fibre Optic Digital Data Links

- **VLBI Terminal Equipment/Interface**
  - VLBI Data
  - Transient Data
  - Visibility Data

- **Super-computer Hardware, Software**
  - Advanced Data Storage

- **To Regional Science Centres**

- **Signal Chain talk**
- **SW Talks**
Correlator Beamformer (CBF)

1. Band-specific Very Coarse Channelizer (VCC)

2. Band-specific Very Coarse Channelizer (VCC)

Frequency Slices

Function-configurable Band-invariant Frequency Slice Processor-1 (FSP-1)

Function-configurable Band-invariant Frequency Slice Processor-2 (FSP-2)

FSP-N

Output Switch

Visibilities to SDP
PSS Beams
PST Beams
VLBI Beams
VLBI visibilities

FSP-1 Data products
FSP-2 Data products
FSP-N Data products
Correlator features

- Frequency-slice Architecture
- Modular, scalable design
- TALON bespoke boards (FPGA) used for VCC and FSP

☑️ Signal Chain talk
CBF Hardware concept

LEGEND
- VCC-Part
- FSP-Part
- Monitor & Control
- TALON System
- 370 TALON LRUs
- 27 Racks with up to 15 TALON LRUs per rack + 1 M&C Rack

CBF Hardware concept diagram with text and symbols showing data flow and system components.

- Streaming data from SKA1_Mid Receptors
- Output to SDP
- VCC-UNIT 5 TALON LRUs
- VCC Processing for 10 Antennas
- Output to SDP
- Output to Mid.PSS
- Output to Mid.PST
- VCC-Part: 19 VCC-UNITS 1 PARTIAL-VCC-UNITS 99 TALON LRUs
- 1G Ethernet to all LRUs
- 1G/10/40G Ethernet Switches
- Mid.CBF Control Server
- 40GbE
- 40GbE to Mid.LMC

FSP-UNIT 10 TALON LRUs
- FSP-Part: 27 FSP-UNITS (26 Active + 1 Spare) 270 TALON LRUs
SAT Architecture

- 3 x redundant Masers
- Steered to align with BIPM
- Timescale 3.0 to 4.8 ns absolute accuracy to UTC
- 1PPS distributed via White Rabbit solution
- Delay correction loop for fibre in SAT.FRQ
- Overall system coherence loss meets requirement
SKA1 & MeerKAT integration

- MeerKAT Precursor
- Infrastructure, Dish, SaDT
- Number of SKA1 Dishes deployed
- Array Assembly 1
- Array Assembly 2
- Array Assembly 3
- Array Assembly 4
  - Precursor Integrated
- Full Handover to Operations SKA1
- Back-End Functionality (CSP, TM, SDP)
Achieving Operational Availability

MTBF/MTTR per item

Maintenance Plans

Maintenance models

Operational Availability Estimate

- Ops talks
SKA1 Multinational Project

Well done!!
Thank you!

Questions?

g.swart@skatelescope.org
Figure 4 Simplified schematic of the STFR.FRQ Transmitter Module, fibre link, and Receiver Module from STFR.FRQ DDD
Timescale Architecture

Legend:
- 100 MHz
- 10 MHz
- 1 PPS
- Data

Exploring the Universe with the world’s largest radio telescope
Correlator Beamformer (CBF)

- **Function-Configurable Band-Invariant Frequency Slice Processor-1 (FSP-1)**
- **Function-Configurable Band-Invariant Frequency Slice Processor-2 (FSP-2)**

**Passive Interconnect**

- **Band-specific Very Coarse Channelizer (VCC)**
- **Visibilities**
  - PSS Beams
  - PST Beams
  - VLBI Beams

**Band-invariant processing (FSPs)**

- **200 antenna FSP-m**
- **200 antenna FSP-n**
- **200 antenna FSP-q**
- **200 antenna FSP-r**

**Frequency overlap via oversampling**

- **FSP-N**

**Band-specific processing**

- Very Coarse Channelizer (VCC)

**All Sub-Arrays**

- Normal imaging visibilities
- Normal imaging visibilities
- PSS beams
- Zoom visibilities

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