SKA WBSPF-AIP
Agenda

• WBSPF Consortium Partners
• Organization and WBS
• General Scope of Work
  – WBSPF advantages
  – Frequency band definition
• Schedule and milestones
• Technical overview
WBSPF CONSORTIUM PARTNERS
SKA WBSPF Countries and Institutions

- **Sweden**
  - Onsala Onbservatory – Consortia lead, integration, system tests
  - Chalmers/MEL – LNA design
  - Chalmers/S2/Antenna group - feed design

- **China**
  - JLRAT – overall management
  - NAOC – Feed and LNA design
  - CETC54 – Feed design, integration and tests
  - IPC – small Turbo-Brayton Cryo Cooler
  - SHAO – LNA design
  - Caltech – LNA design and Feed/Cryogenic consultancy

- **Germany**
  - IAF – MMIC processing
  - MPI – LNA design and testing

- **Netherlands**
  - ASTRON – cryogenics and system tests

- **Turkey**
  - Ozyegin University – feed design
Experience and linkages

Experience

• Experience in building receiver systems at national radio astronomy institutes
• Experience at national institutes and universities in developing very wideband LNA
• Work done in the feed community in support of the VLBI2010
• WBSPF built at single dish radio telescopes (i.e. at Effelsberg 100m) or planned (i.e for FAST)
• Design work for PrepSKA on the Eleven feed done under contract between Chalmers University and the former SKADO

Consortia linkages

• Large overlap in membership between SKA-WBSPF and SKADC
• Chalmers is involved in SKADC Band 1
• Linkage with SKADC in the area of antenna optics
• IAF Fraunhoffer and Chalmers MEL are identified within SKADC as possible sources of LNAs for bands 3, 4 and 5
Lead organisation and Key people

Lead organisation
Chalmers/Onsala Observatory

Formal Head of Project/Project Scientist
John Conway

Project Manager
Miroslav Pantaleev

System engineer
Bhushan Billade

Dish optics
Marianna Ivashina

Band A
System Engineer
Jin Chengjin

Band B
System Engineer
Bhushan Billade
Wide band single pixel feeds (WBSPF) engineering management

Wide band single pixel feeds System Engineering

Performance modelling

Study of available WBSPF

SKA.TEL.WBSPF.MGT
Wide band single pixel feeds engineering management

SKA.TEL.WBSPF.SE
Wide band single pixel feeds System Engineering

SKA.TEL.WBSPF.SE.PA
Product Assurance

SKA.TEL.WBSPF.SE.IM
Interface Management

SKA.TEL.WBSPF.SE.MOD
Performance modelling

SKA.TEL.WBSPF.SE.STUDY
Study of available WBSPF

SKA.TEL.WBSPF.R&D
Wide band single pixel feeds R&D

SKA.TEL.WBSPF.R&D.BandA
R&D Band Low

SKA.TEL.WBSPF.R&D.BandB
R&D Band High

SKA.TEL.WBSPF.R&D.BandA.LNA
LNA design 0.3-2GHz

SKA.TEL.WBSPF.R&D.BandB.LNA
MMIC for 2-10+GHz

SKA.TEL.WBSPF.R&D.BandA.FEED
Band LO feed design

SKA.TEL.WBSPF.R&D.BandB.FEED
Band HI feed design

SKA.TEL.WBSPF.R&D.BandA.CRYO
Cryostat Band Low

SKA.TEL.WBSPF.R&D.BandB.CRYO
Cryostat Band High
JLRAT: overall management, Receiver integration, Testing on the Dish
### WBSPF Consortium partners, Signatories and FTE committed (as at RfP submission)

<table>
<thead>
<tr>
<th>Partner</th>
<th>Type</th>
<th>Contact</th>
<th>Lol Signatory</th>
<th>FTE-yr Committed</th>
<th>FTE-yr Tentative</th>
<th>Material Cost and Travel</th>
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<tr>
<td>Chalmers University - Sweden</td>
<td>Full</td>
<td>Miroslav Pantaleev</td>
<td>Hans Olofsson</td>
<td>4.5</td>
<td>2.25</td>
<td>247</td>
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<td>JLRAT – China</td>
<td>Full</td>
<td>Jan</td>
<td>Hao Jinxin</td>
<td>4</td>
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<td>Fraunhofer - Germany</td>
<td>Full</td>
<td>Fabian Thome</td>
<td>Oliver Ambacher</td>
<td>1</td>
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<td>MPIfR - Germany</td>
<td>Full</td>
<td>Reinhard Keller</td>
<td>Michael Kramer</td>
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<tr>
<td>ASTRON</td>
<td>Associate</td>
<td>Jan Geralt bij de Vatte</td>
<td>Michael Garrett</td>
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<td>0.35</td>
<td>16</td>
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<tr>
<td>Ozyegin University - Turkey</td>
<td>Associate</td>
<td>Ahmed Akgiray</td>
<td>Reha Civanlar</td>
<td>0.4</td>
<td>0.2</td>
<td>0</td>
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<td><strong>Totals</strong></td>
<td></td>
<td></td>
<td></td>
<td>10.95</td>
<td>5.6</td>
<td>3.5</td>
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</table>
WBSPF AIP
GENERAL SCOPE OF WORK
Advantages of WBSPF

Science advantages

- Wide z space for blind HI and OH
- Simultaneous observations of multiple spectral lines, including multiple molecular rotational lines
- Higher bandwidth giving higher sensitivity for continuum observations surveys increasing survey speed
- Advantages for observing fast continuum transients
- WBSPF can search (or time) simultaneously pulsars at a very wide range of galactic dispersion measures along some lines of sight
- Higher probability of serendipitous discoveries including SETI signals
Advantages of WBSPF

System and Operational advantages

• Capital costs- for any reasonable budget dish costs for SKA2 must be pressed down
• Fewer bands per dish will give less power consumption
• Maintenance costs- manpower in remote locations is expensive
• Reducing failure rates –fewer bands per dish
• Therefore extremely important to limit operations costs
FREQUENCY BAND DEFINITION
Considerations

**SKA1 baseline requirements**

- Continuous frequency coverage
- For the 350MHz – 20GHz a range of 57:1, two ultra-wideband feeds 7.5:1 are needed
- Frequency range would be:
  - Band A 0.30 – 2.6GHz
  - Band B 2.60 – 20.0GHz
- Lower band (Band A) would encompass all red-shifted HI, OH and non-galactic centre pulsar work
- Upper band (Band B) would cover most molecules of the Cradle of Life science goal and detection and timing of pulsars toward the galactic centre

**Practical considerations as presented in tender**

- Using the dish in 0.30-0.35GHz frequency range, not covered by SPF Band 1
- Sky noise contribution
- Cooling of feed Band A
- Feed B cryogenic integration about 1.6GHz
- Overlaps SPF Band 3 frequency:
  - Band A 0.30 – 2.0GHz
  - Band B 1.60 – 12.0GHz
WBSPF Band B alternatives

- Option 1: Original proposal in tender.
- Option 2: Similar to VLBI2010.
- Option 3: pulsar timing towards galactic centre, redshifted CO(1-0), Galactic and redshifted H20, large molecules in interstellar medium.
General Scope of Work

• Derive functional and performance requirements for the WBSPF technology;
• Design and analysis of the WBSPF technology, with a view to meeting the required Aeff/Tys performance in SKA dish optics;
• Derive cost model and analyse how performance and costs changes with increasing fractional BW.
• Use the developed cost model to provide information to SKAO on construction, operation and schedule constraints.
• Optimize the design taking advantage of the most economic and efficient industrial methodologies and thereby ensuring competitive costs.
SCHEDULE AND MILESTONES
WBSPF AIP High-Level Schedule

- WBSPF AIP requirements definition - 2013-12-20
- Bands A and B Feed Design Report - 2014-08-31
- LNA modules for integration with the Band B feed - 2014-12-31
- Bands A and B Feed Test report - 2015-03-31
- SRR and PDR data package - 2015-06-15
- Bands A and B cryogenic package test report - 2016-03-01
- Testing on Dish Report - 2016-03-31
- PDR data package - 2016-07-01
TECHNICAL OVERVIEW
WBSPF alternatives

The ATA Feed
- Allen Telescope Array or ATA
- Frequency: 0.5 to 11.5 GHz
- The -10dB HBW = 43°
- Phase Center is frequency dependent
- Size: 0.3 m x 0.3 m x 1.2 m
- Good Match, better than -14 dB

QSC-Feed
- Frequency: >10:1 Bandwidth
- The -10dB HBW is ~ 65°
- Phase Center is frequency independent
- Now Compact Size ~ (0.75λ_max)^2 x 0.2 λ_max
- Input Matching better than ~10 dB

Inverted, Conical, Sinuous Antenna over a Ground Plane
- Frequency: 10:1 Bandwidth
- The -10dB HBW is ~ 65°
- Phase Center is frequency independent
- Size ~ (λ_max)^2 x ? λ_max
- Input Matching better than ~8? dB

Non-planar log-periodic antenna feed for integration with a cryogenic microwave amplifier, G. Engargiola
Page(s): 140 - 143 vol.4


The Inverted, Conical, Sinuous Antenna over a Ground Plane, Rohit S. Gawande and Richard F. Bradley. URSI 2007 Ottawa, Canada, July, 2007
WBSPF overview - Eleven Feed

- Frequency band up to 11:1
- The -10dB HBW ~ 62°
- Phase Centre is frequency independent
- Compact size - \( \varnothing 0.65 \lambda_{\text{max}} \times 0.2 \lambda_{\text{max}} \)
- Input matching better than -12dB
- Good beam and polarisation symmetry

<table>
<thead>
<tr>
<th>diam. 785mm, height 311mm</th>
<th>diam. 280mm, height 68mm</th>
<th>diam. 210mm, height 68mm</th>
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</thead>
<tbody>
<tr>
<td>0.4-1.5GHz</td>
<td>1.2-10GHz</td>
<td>1.2-14GHz</td>
</tr>
</tbody>
</table>

Challenges:
- Complicated feeding
- Work well over small F/D range

**WBSPF overview - QRFH**

- Frequency band near-constant beam width over 5:1 to 7:1 frequency ranges
- The -10dB HBW can be designed for the range of 25-75°
- Compact size - $\phi 1.1 \lambda_{\text{max}} \times 1.2 \lambda_{\text{max}}$
- Input matching better than -12dB
- Can be optimised for wide F/D range

**Challenges:**
- Polarization and beam symmetry

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Challenges of WBSPF

Performance issues

• Lower sensitivity than octave feed horn
• Some degradation in performance if they are made very wide band
• We believe the gap in performance can be narrowed given further R&D

Relative merits of octave horns versus WBSPF

• Full ‘cost of ownership’ analysis including
• Initial investment
• Operations costs
TECHNICAL OVERVIEW – BAND A
Feed candidates for Band A – 0.3 -2GHz

0.4-2GHz UWB feed for CSRH. Dimensions 465mm x 465mm x 185mm (h).

QRFH for, preliminary design by Caltech for FAST (F/D = 0.461) for 0.27 to 1.62 GHz.

Size 1m x 1m x 0.83m.
LNA — 0.01-2GHz

- Caltech CITLF2 SiGe low noise amplifier.
- The noise and gain data is measured at 22K with DC bias of 2.5V and 22mA.
- Input and output return loss are better than 10 dB.
- The design will be further optimized for FAST and SKA frequency bands.
Band A – 0.3 -2GHz - cryogenic integration

- Cryostat housing the LNA
- Either SiG or InP LNA
- Either 20K or 60K cryostat
- The table below shows the noise budget for either physical temperatures

<table>
<thead>
<tr>
<th>Cryostat Temp, Tphy</th>
<th>LNA Noise</th>
<th>Loss at Tphy, dB</th>
<th>Noise Added by Lphy</th>
<th>Transition Loss, dB</th>
<th>Noise Added by Transition</th>
<th>Cable Loss, dB</th>
<th>Noise Added by Cables</th>
<th>Total Noise at Feed Connector</th>
<th>Ant Temp</th>
<th>Tsys, K</th>
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<tbody>
<tr>
<td>60</td>
<td>10</td>
<td>0.4</td>
<td>6.2</td>
<td>0.1</td>
<td>4.5</td>
<td>0.1</td>
<td>7.3</td>
<td>28.0</td>
<td>15</td>
<td>43.0</td>
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<tr>
<td>20</td>
<td>4</td>
<td>0.4</td>
<td>2.1</td>
<td>0.1</td>
<td>3.8</td>
<td>0.1</td>
<td>7.1</td>
<td>17.0</td>
<td>15</td>
<td>32.0</td>
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</table>
Turbo-Brayton Cooler – 2-5K – 200K

- Great reliability: operating lifetimes without maintenance of over 100,000 hours (~11 years)
- Reduced vibrations: low level of vibration (a few µg at 1500 Hz)
- Simplify the cryostat design
TECHNICAL OVERVIEW – BAND B
Feed candidates for Band B – 1.63 - 12GHz

- Both feeds are well developed for the VLBI2010
- The efficiency in the above plot is for 12m Cassegrain antenna with ring focus sub-reflector.
Feed candidates for Band B – comparison

<table>
<thead>
<tr>
<th></th>
<th>Eleven</th>
<th>QRFH</th>
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<tbody>
<tr>
<td><strong>Frequency range (GHz)</strong></td>
<td>1.2-14</td>
<td>2.2-14</td>
</tr>
<tr>
<td><strong>Polarization</strong></td>
<td>Dual-Linear</td>
<td>Dual-Linear</td>
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<tr>
<td><strong>Port Configuration</strong></td>
<td>Differential</td>
<td>Single-Ended</td>
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<tr>
<td><strong>LNAs per Polarization</strong></td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td><strong>LNAs per Feed</strong></td>
<td>8</td>
<td>2</td>
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<tr>
<td><strong>LNA Balance Requirements</strong></td>
<td>1.6 dB amp</td>
<td>None</td>
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<tr>
<td></td>
<td>14° phase</td>
<td></td>
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<tr>
<td><strong>Aperture Efficiency</strong></td>
<td>60-70% (1-10GHz)</td>
<td>55-65% (2-10GHz)</td>
</tr>
<tr>
<td></td>
<td>50-60% (10-14GHz)</td>
<td>45-55% (10-14GHz)</td>
</tr>
<tr>
<td><strong>Ground Noise Contribution</strong></td>
<td>Preliminary 10-20K, but more research is needed</td>
<td>&lt;20K (2.2-5 GHz)</td>
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<tr>
<td></td>
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<td>&lt;10K (5-14 GHz)</td>
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<tr>
<td><strong>F/D Range</strong></td>
<td>0.35-0.5</td>
<td>Adaptable for nominal 0.3-0.7</td>
</tr>
<tr>
<td><strong>Feed 10-dB half-beamwidth</strong></td>
<td>65°</td>
<td>Adaptable for nominal 55°-140°</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Diameter 210mm height 65 mm</td>
<td>diameter 160mm height 150mm</td>
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</table>
Feed Band B design optimisation

- SKADC will fix the design of the dish after CDR in spring 2014.
- MATLAB code runs CST or FEKO to iterate over space of design parameters.
- Evaluate the best design for given design goal.
- Verify the performance in given Antenna optics design using FEKO or GRASP.
- Verify the Receiver noise using MATLAB code.
- Calculate $E_{eff}/T_{sys}$.
- Verify polarimetric performance.
Band B cryogenic Integration

- Vacuum window 0.35mm thick Mylar
- Deflection of about 25mm
- The location of the Feed is determined by the deflection of the window
LNAs for Band B

- Two foundries are involved: IAF from Germany and MEL from Sweden
- Designs will be made for InP processes in both foundries
- Designs will be made for 50ohm single ended and 100ohm differential inputs of the LNA

Measured typical performance of MEL/LNF LNA
LNAs for Band B alternative 3-22GHz

- Commercially available from Low Noise Factory
- 6-22GHz, room temperature
- More than 800pcs. sold to customers
- 4-16GHz - cryogenic
- Design for 3-22GHz is possible with gain degradation towards edges of the band.