SKA Update & Engineering Opportunities
SKA-Japan Workshop

P. Dewdney
Nov 4-5, 2010
Multiple Receptor Technologies

Dense Aperture Arrays

3-Core Central Region

Sparse Aperture Arrays

Dishes

How to Span the Huge Wavelength Range!
Artists’ Renditions from Swinburne Astronomy Productions
Sparse aperture arrays for the lowest frequencies

LOFAR (Netherlands et al)

LWA (USA)

Replication by Industry

MWA (USA, Australia)
EMBRACE Prototype for Dense Aperture Arrays

Industry already involved in production.

First Fringes
New Technology for Dishes

**ATA**
- 42x6m hydroformed dishes

**KAT-7**
- 7 x12m composite dishes

**ASKAP**
- 36x12m panel dishes

**CART**
- 10 m composite prototype
Multi-pixels at mid frequencies with dishes + phased-array-feeds

ASKAP, Australia
Chequer-board phased array (ASKAP, Australia)

APERTIF (Astron, NL)

DRAO Canada
Vivaldi arrays
Single pixel wide band feeds

Quad ridge Lindgren horn

Polyethylene Window
Feed
15K Plate
LNA's
Cryocooler

Quasi Self Complementary feed

ATA feed

Chalmers “Eleven” feed

From German Cortes

Inverted conical sinuous feed
Engineering Characteristics of the SKA

• Scale: SKA is “Big Science”.
  – Wide international participation, complex financing & procurement.
  – Moderately complex technology.
  – Estimated investment 1500 M€.
  – Japan should be involved in all big global science projects.

• Remote Site
  – Many remote-site operations in astronomy,
  – Will be partly developed by Pathfinders.
  – Widely distributed site with a variety of local conditions.
Engineering Characteristics

- Construction & observations to co-exist for many years
  - “progressive rollout”.
  - RFI to be minimized.
    - No. of on-site people to be minimized.
  - Deployment of equipment in ready-to-use, connectable blocks.
  - Possibly continuously upgraded.
  - Very large operational site.
    - Operations by remote monitoring and control.
  - Maintenance challenges.
    - Widely distributed site.
Engineering Characteristics of SKA

• Design Lifetime
  – Telescope typically lasts for 20-30 years, but
    ▪ Continuous addition of collecting area.
    ▪ Upgrading and replacement over time.
    ▪ Occasional signal processing equipment replacement.
  – A design lifetime specification will be needed for each array sub-system.
  – Site could be used for 100’s of years.

• Large power requirement.
  – Power to be delivered at the central core as well as to remote stations.
SKA1 Configuration

20 km
SKA1 Dish Configuration

5 km
Dishes
Blue: SKA1 Configuration
Red: SKA2 Configuration
SKA2 Configuration

VLA Scale

50 km
SKA Project Office is instantiating a system engineering approach to SKA design.

- Strongly indicated by the engineering characteristics outlined earlier.
- "New". Not a strong tradition of system engineering in radio astronomy.

Only “tried and true” method of sorting out:

- matching technology to science.
- selecting competing technologies,
- optimising allocation of resources,
- tracing decisions from requirements to implementation,
- managing project changes,
- incorporating new technology on a rational basis.
SKA Opportunities

- **For governments:** The SKA will create jobs, wealth, and knowledge in their constituencies.
- **For academia:** Access to the SKA will provide must-have opportunities for research.
- **For industry:** Access to contract opportunities that will
  - broaden capabilities,
  - develop highly qualified personnel,
  - create new industrial partnerships,
    - transportable to non-science sectors,
    - SKA is highly networked.
- Radio astronomy has a long record of
  - adapting new technology to astronomy (sophisticated users),
  - contributing to “spinning out” technology into society.
- This record will continue apace and even quicken with the SKA.
Technical Opportunities
Telescope Components – Signal Path

Summary of Opportunities in the SKA Signal Path

Antenna → Feed Hardware → RF Electronics → Short-haul Links → Station Electronics

Concentrator
Feed Support

Feeds
Cryogenics
Enclosures

LNA
Down-conversion
LO
Beamforming

Fibre
Opto-electronics

Filterbanks
Beamformer
Stn Correlator

Long-haul Links → Central DSP → Computing → Archive, Distribution

Fibre
Opto-electronics
Optical Amplifiers

Filterbanks
Beamformers
Correlator

Hardware
[Software]
Nominal upper frequency for SKA is ~10 GHz.

- Some inherent limit to “wide” bandwidth.

But note Lazio talk:

- Redshifted CO.
- “pebbles” in protoplanetary disks.
- Deep penetration of “high-tau” stellar disks.
- “Heavy” molecules.
- Pulsars at Galactic Centre.

These non-HI science topics tend to push frequencies higher.
**Wideband Systems – Dish Feeds**

- “Standard” high-performance feeds for dishes have bandwidth ratios $\approx 2:1$ ratio of upper-to-lower frequency.
- Research from SKA Technology Development Program (US TDP) trying to obtain ~10:1, but efficiency is not as high as standard feeds.
  - Represents an SKA research opportunity in very wide-band systems.
  - Careful integration of LNA with the feed is essential.
  - Important performance aspects:
    - Symmetry of feed pattern.
    - Polarisation.
    - Stability is critical.
- PAFs do not have very wide RF bandwidths, but the total bandwidth is very high (see Bunton talk).
  - Potential opportunities for high-performance multi-input ADCs.
Wideband Systems - ADCs

- **Direct sampling/digitised Down-Conversion**
  - ADCs need very wide analog input bandwidth.
  - e.g. Direct conversion from 5-10 GHz could be very cost effective.
  - Post-digitisation filtering.
  - Question: Do we need “strong” anti-aliasing analog filtering?

- **Low statistical bias very important.**
  - e.g. Interleaved samplers often create artefacts.

- Low power quite important.
  - Overall system power is extremely important.

- **Direct digital down-conversion could be very efficient and low cost, if good ADCs can be obtained.**
Design Environment for Dish RF Systems

Field Replaceable RF Enclosure for Two RF Chains (two polarizations)

- Shielded enclosure – ideally only two electrical connections (power & RF input).
  - All components mounted on temperature controlled plate, possibly at ~50°C.
    - Temperature sufficiently high that active cooling is not required.
- Input from LNA(s).
- Contains RF amplification, frequency conversion (if present), ADC(s) (if present), framing (if present) and optical modulation.
- Heat extract from passive radiation techniques and/or phase-change materials.
- One or more to be mounted on antenna.
- Size to be determined by contents and other design parameters.
Wideband Systems – Aperture Arrays

- AAs are lower bandwidth than dishes
  - But there are many interesting challenges for the signal chain design.

- Cost & power consumption.

- ADC properties:
  - Many bits (~8?)
    - RFI.
  - Temperature insensitive.
    - Probably uncontrolled desert environment.
  - Very low power.
    - Many devices consuming power.
  - Easily shielded.
    - Compact design
  - Low cost – possibly multiplexed across many RF inputs.
    - Not just ADC cost – could save on cost of aggregating many signals.
Other Possibilities

- Digital Signal Processing – correlators, non-imaging processing
  - Long history of building correlators in Japan.
  - First FX correlator.
  - Several different digital sub-systems will possibly be needed, depending on the system design.
  - NAOJ ASIC – correlation, non-imaging processing, gridding???

- Optical data transmission
  - Fibre and optical components and sub-systems.
  - e.g. Sumitomo Electric
SKA Contributions – Industrial Scale

• SKA – An “Iconic” Project for Solar Power

• Array diagrams illustrate the physical scope of the power requirements.
  – Either site will require very large power upgrade.

• Solar power is almost certain to provide some of the power.
  – Possibly all of the power.

• Japanese firms are very active in photovoltaic solar panels.
  – Kyocera
  – Mitsubishi Electric Corp
  – Sanyo
  – Sharp Solar (#3 in the world in solar panel manufacture).

• Power – storage batteries for wind & solar load-leveling:
  – NaS batteries.
  – NGK and Tokyo Electric Power Company (TEPCO)
  – e.g. used by Fujitsu for backup in semiconductor foundaries.
SKA will require a supercomputer

- image processing and possibly non-image processing.
- Even SKA1 will require a large computer.

- From Fujitsu website =>

- Critical number is “flops per u-v point”.

SKA software will probably be “inherited” from existing packages to begin with.

- Experience in Japan with ALMA and the ALMA S/W developers will be a very valuable resource.
- Although we are not yet sure, it seems likely that a very large code base will eventually be needed, which is optimised for supercomputer architectures.
Dynamic Range

- Imaging (and spectral) DR.
  - Rawlings, Lazio talks – 10 nJy and 1000 hrs integration.
- Don’t want to build a supersensitive (high $A/T_{\text{sys}}$) telescope:
  - then find that it hits a limit after few 10’s or hours of integration, which is then an irreducible limit because of systematic errors.
  - i.e. not fully understood, or rapidly time variable.
- High DR is a system issue.
  - need to consider the whole signal chain, signal processing and imaging as a system.
  - Especially potential non-linear devices such as ADCs.
Limitations to Modelling/Cal

- Cannot model and calibrate systematic effects (errors) that are not fully understood.
  - Sounds obvious … but years of work on specific telescopes have typically been required to understand the subtle systematic effects needed to achieve high DR imaging.
  - The lessons learned from this work must be applied to the SKA from the beginning.

- Unprecedented level of collaboration needed for the SKA between design engineers and astronomers (also cross-training).
  - My own experience with VSOP in Japan indicates that the Japanese system already has a strong technology-science collaboration.
  - Japanese radio astronomers have built up quite a lot of experience with aperture synthesis systems: Nobeyama array, ALMA.
A contributor of a particular “technology” to the SKA can only expect to “get value” for their contribution if there are other contributions as well:

- (Obviously) representation on governing councils.
- In the design phase:
  - Involvement at the center in the overall system engineering.
  - Important to have people on both sides of the organisation (central and sub-system contributor).
- In the System Integration phase:
  - People involved in system integration.
  - People on the continuous evaluation teams.
  - Japanese science from the SKA will benefit from “inside knowledge” of how the system operates, calibration, etc.
SKA Industry Relationships-Model

SKA Partners or Consortia
Industry or Industry Consortia

Japan?
Work Package Consortium

Globe

SKA Project Office (Sys. Eng. & Mgt.)
Japan?

Outputs
Work Packages
Summary

- Japan has a “complete” technology base.
  - All aspects of SKA technology could in principle be supplied from Japan.
- **Wide-band technology**
  - ADC performance is critical in many respects.
  - Further work at NAOJ could “target” specific SKA requirements – some of the subtle design aspects of ADCs.
- **Astronomy-specific software development.**
- Broad scope for Japanese technology to provide in-kind contributions in critical areas.
  - Power.
  - Optical communications.
  - Digital signal processing.
  - System engineering.
  - Software and supercomputing.
- Japanese science success advanced by involvement at the system and system-integration/test levels.
- Early involvement will be important, even at a low level.