THE SQUARE KILOMETRE ARRAY (SKA) PROJECT: AN INTERNATIONAL ENGINEERING PERSPECTIVE

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ABSTRACT

The pace of the international Square Kilometre Array (SKA) project is accelerating, with major concept reviews completed recently and a number of technology demonstrators underway. First-round submissions to host the telescope, incorporating initial radio-frequency environment measurements, have been lodged by four countries, including Australia. The SKA timeline currently shows a site being selected in 2006, and one or more technology concepts chosen in 2007 – 2008. The telescope is expected to be operational, in various phases, in the period 2015 – 2020. This paper gives a status review of the project, with an emphasis on engineering concept development and demonstration.

INTRODUCTION

At WARS 2000 I gave an invited paper describing the SKA radio telescope project [1], an international project to build an aperture synthesis radio telescope with 1 million square metres of effective collecting area and operating in the range 100 MHz to 22 GHz. An update in 2002 [2] mentioned that the number of countries involved had increased from 7 to 11, and that the budget had doubled from USD 500M to USD 1B. International participation continues to increase, with 15 countries now represented on the International SKA Steering Committee (ISSC). The budget remains at USD 1B, notwithstanding much more detailed costings contained in a series of recently-completed concept expositions, or whitepapers. The first international Director and Project Engineer commenced appointments in 2003 and 2004, respectively.

The whitepaper, or end-to-end concept description, process has proved invaluable in promoting science and engineering discussion, identifying areas in which there are deficiencies in knowledge or specification clarity, and stimulating new studies – including simulation of performance and cost tradeoffs. In effect, the whitepapers are slices through a complex problem and solution space, the sample solutions being used to illuminate critical issues and to arrive at still more imaginative answers. All whitepapers are available on-line at [3].

A less glamorous, but very important, aspect of SKA engineering deals with site infrastructure design and costing. Four proposals have been received from countries wishing to host the telescope and an initial costing study [4] puts the infrastructure value of the project at around USD 250M, including optical fibre network.

WHITEPAPERS AND CONVERGENCE

One of the main outcomes of the whitepaper preparation and review processes has been the recognition that no one concept meets all the SKA performance goals. In particular, cost-effective designs meeting the high-frequency sensitivity requirements are unable to give adequate sensitivity at low frequencies, nor to provide the independent multi-fielding (or area re-use) capability which is now established as an SKA target. Importantly though, the whitepapers did establish the commonality of a large amount of the SKA system design, independent of the selected antenna or associated RF technology. A design convergence process is therefore underway, involving astronomers and engineers working iteratively to explore the assumption that a hybrid – or composite – telescope will give a better match to the science goals. In this model, at least two antenna solutions share common sites, signal transport and back-end infrastructure.

While the hybrid model is promising, its elements will come from technologies described in the whitepapers. In parallel with the convergence work, a number of engineering groups are therefore working to validate pivotal technologies by means of demonstrators, of various scales. The intention is to have critical technology reviews form the basis of a 2007 – 2008 concept selection process.

SKA CONCEPTS

There are currently seven antenna concepts for the SKA under active consideration and prototyping. Table 1 aggregates these by form and summarizes some key features, while Fig. 1 is a visualization of various instruments. It is important to realize that the SKA is much more than antennas, requiring as it does major developments in fields such as low-noise integrated RF systems, long distance data transmission at Tb/s rates, real-time signal processing at peta operation per second speeds, and highly complex computing systems spanning a number of software engineering fields. Still, apart from being the most visible part of the telescope, antennas will account for 40 – 50% of the cost, despite intentions to make a "software telescope" by exploiting, as far as possible, the convergence of radio and computing.

Table 1. Summary of SKA Concepts

Concept Class	**Type**	**Attributes**	**Challenges**	**Demonstrators**
Large diameter reflecting flux concentrators (30-100 antennas = stations)	Large Adaptive Reflector (LAR). Kilometre-area Radio Synthesis Telescope (KARST). Cylindrical Reflector (CR).	Filled station (high sensitivity to spatially extended radio emission). Small N → lower infrastructure costs. Potentially wide frequency coverage.	Advanced focal plane arrays for acceptable field-of-view. High fidelity imaging with small N.	Scaled aerostat and control system. Five hundred metre Aperture Spherical Telescope (FAST). SKA Molonglo Prototype (SKAMP).
Medium diameter reflecting flux concentrators (4500 – 8000 antennas, N=600 stations)	Large N – Small D array (LNSD). Pre-loaded Parabolic Dish (PPD).	Large N → good imaging. Good high-frequency sensitivity. Highly versatile array. Wide frequency coverage.	No multi-fielding. Poor low-frequency sensitivity.	Allen Telescope Array (ATA). Raman Research Institute 12 m antenna.
Refracting flux concentrator (20 000 antennas, N=300 stations)	Luneburg Lens (LL)	Multi-fielding to 10 GHz (quasi-optical beamforming).	10 GHz upper frequency limit. New dielectric material required.	Small Luneburg Antenna with New Dielectric (SLAND)
Aperture Phased Array (~200 000 elemental antennas, N=100 stations)	Aperture Array Tile (AAT)	Multi-fielding to 1.5 GHz (electronic beamforming)	1.5 GHz upper frequency limit. Low-cost realization needed.	Thousand Element Array (THEA). Electronic Multi-Beam Radio Astronomy Concept (EMBRACE).

It is obviously possible to divide the 10^6 m^2 of collecting area in many ways and the descriptions given in Table 1 are indicative of those so far investigated by proponents of various concepts. The idea of a "station", representing a patch of collecting area, is basic to all designs. The number of stations, N, is a useful design classifier: large-N (N>300) and small-N (N<50) concepts may offer relatively high-fidelity imaging and low infrastructure costs, respectively. However, a series of simulations to illuminate the trade-offs in large/medium/small-N designs is still in progress.

The proposed LOFAR telescope, a phased array operating in the 10 – 250 MHz range, would be an invaluable additional SKA demonstrator in areas such as RF interference mitigation and large-N calibration.

Fig. 1. SKA concepts. The left panel shows two large adaptive reflector ideas, one based on a 200 m diameter Arecibo-like spherical reflector (upper), the other using a much flatter reflector and an aerostat mounted focus cabin. The middle panel (upper) shows proposed 12 m diameter offset paraboloids, similar to the 6 m versions used in the Allen Telescope Array; the lower illustration shows a single-polarization Vivaldi-horn aperture phased array antenna under test. The right panel (upper) shows a station based on 64 x 7 m diameter Luneburg Lenses; the lower visualization is of a station employing a single 110 m x 15 m cylindrical reflector. The concepts originate in China, Canada, the USA, Europe and Australia (both right hand panels). Not shown is a 12 m symmetrical paraboloid proposed by the Indian SKA group.

PIVOTAL TECHNOLOGY

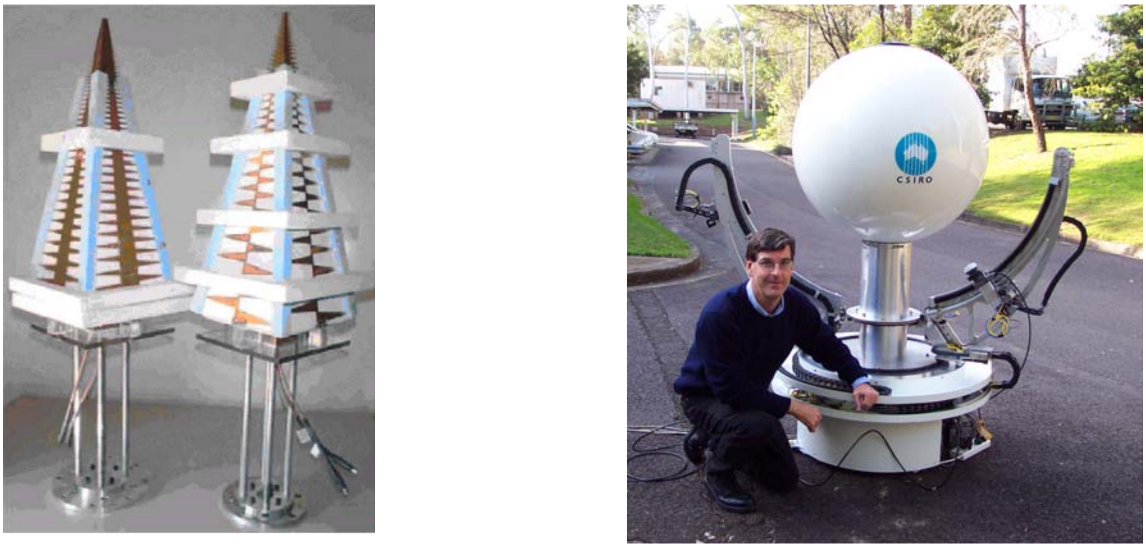
A recent review [5] of updated SKA whitepapers produced a series of critiques for the various concepts and flagged the major engineering challenges to be addressed in demonstrators. This list includes items such as:

- Low-cost manufacturing methods for both concentrators and dense aperture arrays;
- Sensitive, cheap, highly-integrated, uncooled receivers (Aperture Array, Luneburg Lens, Cylindrical Reflector);
- Efficient, broadband, feeds with optical arrangements yielding minimum spillover (concentrators);
- Low cost, reliable, cryogenics (concentrators other than Luneburg Lens and Cylindrical Reflector);
- Large, cheap, focal plane arrays with accurate, low-loss, beamforming networks operating to beyond 10 GHz (large concentrators);
- Economical, high bandwidth (Tb/s), fibre optic signal transmission links (compatibility with commercial standards and maximum bandwidth efficiency are different dominant issues in distant and central SKA distance regimes, respectively); and
- Scaleable signal processors – including correlators – which demonstrate processing power, flexibility and connectivity issues.

While much remains to be done, there have been some notable engineering achievements already. A sampling of the 2002-2003 engineering highlights reported in [5] includes items such as:

- Broadband log-pyramidal feeds covering the range 0.5 – 11 GHz (Fig. 2a);
- New methods of accurately hydroforming aluminium paraboloids;
- Development and test of new pulse-tube cryogenic coolers operating at 80 K;
- Decade-band, low-noise, RF amplifier development, both cooled and uncooled, using technologies ranging from indium-phosphide to CMOS;
- Refinement of cost-effective, light-weight, dense focal plane arrays using Vivaldi end-fire elements;
- Active controls and new manufacturing methods for large reflectors (> 200 m diameter); and

- New low-loss artificial dielectric material (tan δ $< 10^{-4}$) for Luneburg Lenses and other e.m. applications, together with an associated feed translation system for lenses (Fig. 2b).



(a) (b)

Fig. 2. (a) Broadband feeds developed by the Allen Telescope Array project in the USA. The feeds are about 1.2 m long and cover the band 0.5 – 11 GHz. Cryogenically cooled low-noise RF amplifers are mounted within each pyramid. (b) A prototype Luneburg Lens two-arm feed translator developed by CSIRO for its 0.9 m lens.

CONCLUSION

With many innovative concepts proposed for the SKA the selection process relies heavily on demonstration of key systems and components. While far from uniform in scale, demonstrators currently being built will give insight into the feasibility of various approaches. Despite the size differences, all of the demonstrators listed in Table 1 will yield astronomically or commercially significant outcomes. A large-scale, on-site, demonstrator using selected technologies will most likely be built in the period 2008 – 2015, minimizing the “leap of faith” to the SKA. At perhaps 20% of the SKA area, this telescope will be a formidable instrument in its own right, possibly revealing, for example, the equation of state (pressure/density relationship) of the Universe.

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REFERENCES

[1] P. J. Hall, “The Square Kilometre Array Radio Telescope”, Proc. WARS 2000, pp. 41-46, April 2000.
[2] P. J. Hall, “The SKA: Australian Directions”, Proc. WARS 2002, Feb. 2002.
[3] International SKA whitepapers, May 2003 (available at http://www.skatelescope.org/documents/dcwp.shtml).
[4] P. J. Hall (ed.) “The SKA: Initial Australian Site Analysis”, submitted to the ISSC, May 2003 (available at http://www.skatelescope.org/documents/swp.shtml).
[5] P. J. Hall (ed.) “Report to the ISSC by the IEMT”, Oct. 2003 (available at http://www.skatelescope.org/documents/index.shtml).