Reflector Antennas (Dishes) for the Square Kilometre Array (SKA)

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Abstract

Parabolic reflectors (dishes) are the most general purpose, flexible antennas used in radio astronomy, typically able with multiple feeds to cover two orders of magnitude in frequency. The SKA requirements will push the limits of dish design for decimetre wavelengths beyond that of any existing dishes. The SKAs sensitivity as well as its wide-field imaging requirements push performance limits, while the need to produce and deploy thousands of dishes in an array spanning continental baselines push cost and fabrication limits. This paper will discuss SKA requirements and a combination of techniques being brought to bear on this design problem.

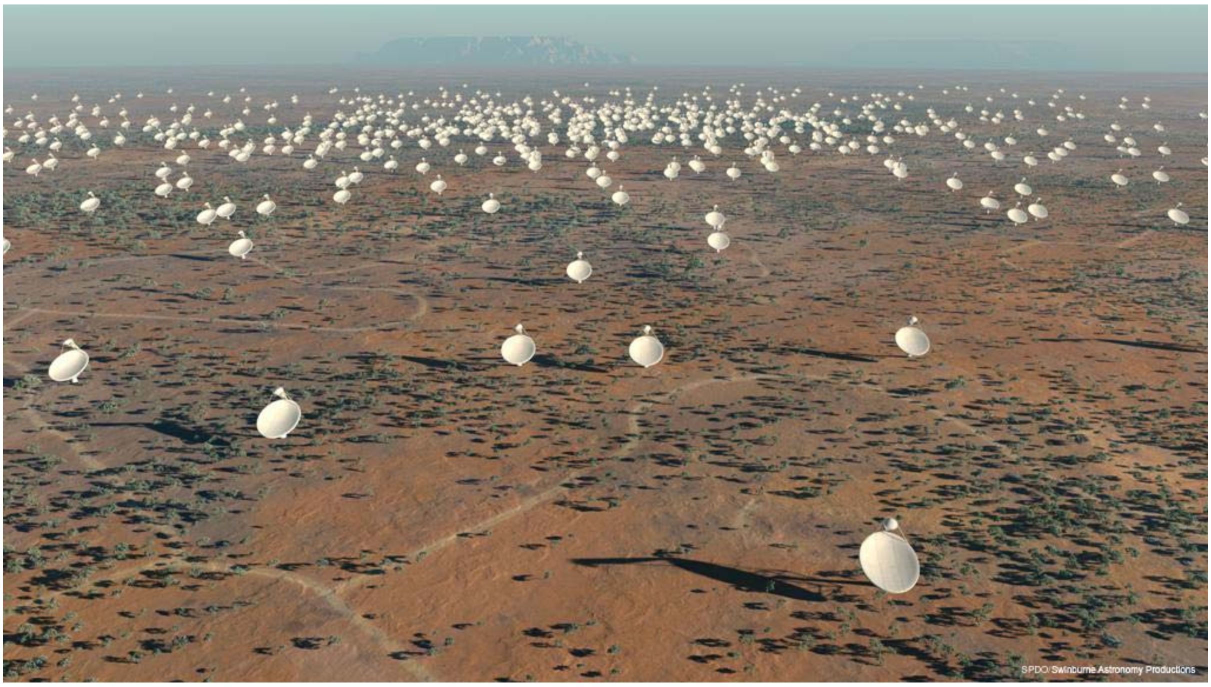

Figure 1: An artist's concept drawing of the SKA dish array. The dishes shown are one of several possible designs.

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1. The need for dishes in the SKA

Large reflector antennas, typically parabolic dishes, have been successfully used for radio astronomy for more than 50 years, so it is perhaps unsurprising that dishes are expected to form a substantial part of the SKA. Raw sensitivity is a strong driver of the SKA system design, but there is also a need to carry out surveys of large regions of the sky. To simultaneously address these two requirements a compromise has been made on the size of the dishes to be used for SKA. If raw sensitivity alone were the concern then a relatively small number of large dishes could be the most cost-effective solution, but smaller dishes with larger field of view offer the prospect of faster surveys of the sky. An effective diameter of 15 metres has been adopted for the SKA dishes to give a reasonable field of view whilst also allowing for the required raw sensitivity at reasonable overall cost of ownership.

2. SKA dish requirements

The first phase of the SKA (SKA1) will contain 250 15-metre dishes. In the second phase (SKA2), the number of dishes is expected to increase to around 3000. Many aspects of the SKA dish-design challenge are without precedent, particularly the large numbers of dishes required, and the huge sensitivity that is expected to result. The main goal is to produce antenna designs with the greatest system sensitivity (A_e/T_{sys}) per unit system cost, while at the same time ensuring that the contribution of antenna-related systematic errors is within acceptable limits. (A_e is the total effective collecting area of the SKA, and T_{sys} is the system noise temperature.) System cost includes not only construction costs, but also operations and maintenance costs.

Whilst maximising the scientific productivity per unit cost is the overriding aim, there are also other functional (associated directly with function) requirements and a great many non-functional (associated with the need to exist in the environment and within other parts of the system) requirements relating to the dish design. One significant source of non-functional requirements is the need to operate and maintain the SKA in a remote, harsh desert environment with a limited maintenance team. The following short list highlights some of the major functional and non-functional requirements.

- **Imaging dynamic range**
  - Imaging dynamic range refers to the ratio of the brightest object in an image to either noise or fluctuations in the image, which limits the detectablility of weak objects in the image. Imaging dynamic range is a telescope system specification.
  - Achieving sufficient imaging dynamic range requires the dishes to have very stable, predictable beam-shape and pointing in extreme desert environmental conditions.
- **Design for mass manufacture**
  - Dishes of the size required for the SKA have never before been manufactured in quantities of thousands. In order to maximise the science return per $/€ significant improvements in design-for-manufacture are needed, compared with existing approaches.
- **Operating cost**
  - Thousands of dish systems will be very expensive to operate unless they are designed for high reliability with minimum maintenance. The maintenance regimes at existing radio astronomy observatories will not be affordable on this scale.
  - Routine maintenance intervals of at least one year are anticipated, including dish mechanics and cryogenics (to cool the low noise amplifiers).

- **Rapid installation**
  - Dish systems will need to be installed rapidly using minimal on□site manpower and equipment.
  - This is to minimize the impact on on-going observations, as well as to keep down the manpower cost.
- **Feed flexibility**
  - The dish design must be capable of deploying multiple single-pixel feeds, as well as having the capacity for a large phased-array feed. No other dish design of comparable size has this capacity.
  - A significant means of improving overall SKA system performance will be obtained through enhancement of feeds and receivers, especially in the transition of SKA1 to SKA2 .
- **Maximum A/T is required**
  - We must maximize sensitivity per €/$ whilst meeting other requirements.

No existing radio telescope has matched these requirements in combination, and the current view is that the dishes will be procured on the basis of a detailed design (fabrication ready, build-to-print), not a performance-specified design.

3. Dish antenna technical design considerations

It is beyond the scope of this paper to go into detail about the SKA dish technical design, but some of the key features are as follows.

- Low contributions to T_{sys}:
  - Low spillover & correlated ground signals,
  - Minimize scattering structures,
  - Cryogenically cooled low noise amplifiers.
- Maximize A_e for a specified sidelobe envelope:
  - Low blockage is one solution.
- Multiple feeds:
  - A_e/T_{sys} and dynamic range have priority over feed bandwidth; therefore more feeds to be accommodated.
- Predictable, time-stable, frequency-smooth and “limited support” beam:
  - Pointing variation within characteristic calibration timescale,
  - Polarization,
  - Gain ripple,
  - No resonant scattering.
- If rotating on the sky with parallactic angle, rotational symmetry of the inner beam pattern:
  - Gain variation within characteristic calibration timescale,
  - Note that the rotation rate can be controlled within limits by avoiding the region around the zenith.

- Low far-out sidelobes:
  - Minimize scattering structures, especially resonant scattering (e.g. slots between panels, wavelength-sized conductive structures in the beam).
- Clean RF signal path:
  - Cable routing and similar practical details.

4. The SKA dish program

The SKA dish development program has as its main purposes:

- design an antenna that can enable the SKA requirements to be met, and can be built in quantity at acceptable cost;
- obtain accurate estimates of volume manufacturing and maintenance costs;
- obtain SKA system costs (including signal transport, signal processing and computing) in areas related to the antenna design (e.g. numbers of antennas);
- verify antenna performance as much as possible;
- verify the ability of the antenna to operate in its intended environment;
- develop calibration and other techniques to mitigate the errors as much as possible;
- understand limitations placed by residual errors on SKA system performance.

It is expected that at least one complete prototype antenna/feed/receiver system will be constructed by the end of 2012. This is expected to be the first of a series of converging prototypes leading to the final SKA dish design.