Dish Verification Antenna China for SKA

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Abstract- **The SKA (Square Kilometre Array), being the next-generation largest radio telescope, has now stepped into the pre-construction phase. China has joined this long march since the early 1990s and made significant contributions during this process. In this paper, a brief review of the SKA concept and detailed description of the challenges for the SKA dishes are given. Then two concept designs for the SKA dishes made by Chinese, the Dish Verification Antenna China (DVAC), are presented. The designs including microwave optics, antenna structure and servo system are carefully carried out to meet the intended SKA requirements. Comparison of these two designs is made in the end and one of them is selected as a candidate for the SKA dishes.**

I. OVERVIEW OF SKA DEVELOPMENT

In 1993, astronomers from ten countries including China proposed to build the next-generation Large Telescope (LT) for in-depth exploration of the universe, and the LT was renamed as the Square Kilometre Array (SKA) later. Once being constructed successfully, the SKA will become the world's largest and most sensitive radio telescope, and will remain in that position for 20~30 years.

Through earlier research and trade-off, two technology roadmaps were developed, that is LDSN (Large Diameter Small Number) and LNSD (Large Number Small Diameter). Five potential engineering concepts for the SKA were proposed including KARST (Kilometre Square Area Radio Synthesis Telescope, by Chinese), LAR (Large Adaptive Reflector, by Canadian), ATA (Allen Telescope Array, by American), AAT (Aperture Array Tile, by Netherlander) and Luneburg lens antenna (by Australian). Considering the technical issues and science requirements, the LNSD roadmap was finally adopted for the SKA.

No single technology has been identified to cover the frequency range from several tens of MHz up to 20GHz. The SKA has been divided into three arrays: the low frequency array that covers the range of 70-300MHz, the mid-frequency array that covers the range of 300 MHz -1.8GHz and the high frequency array that covers the range of 300MHz - 20GHz [1]. In the high frequency array, about 3300 dishes with 15m in diameter for each is adopted as shown in Fig. 1.

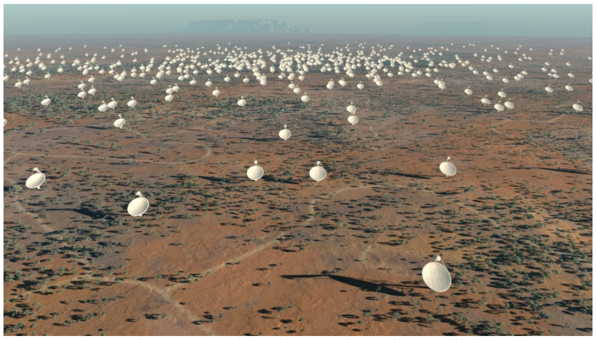
Figure 1. Artist's impression of SKA dishes.

Unprecedented challenges need to be overcome in the SKA dishes design[2,3], that are: very high imaging dynamic range, mass production, ease of transportation, rapid installation with minimum manpower and equipment at remote sites, low operating costs, maximum sensitivity, etc. None of the present dish design will meet all these requirements in combination.

Chinese has presented two concept designs for the SKA dishes DVAC-1 and DVAC-2 [4-6], which are offset Gregorian dish and prime focus symmetric dish, respectively.

II. OFFSET GREGORIAN DISH (DVAC-1)

This section presents the concept design and main specificaitons of DVAC-1, a 15 meter offset Gregorian antenna. The main attractions of this design are as follows.

(a) Offset-Gregorian optics is adopted to enable high aperture efficiency and low system noise temperature.

(b) Wideband single-pixel feed (WBSPF) is used to cover the entire frequency range with less number of feeds.

(c) One-piece main reflector enables fast installation with low man power, and the ajustment is almost free for the shape of the primary.

(d) Sealed and lubricated driving devices are used for high reliability and low maintenance cost.

(e) Wherever possible, mature technology is used for low cost, high reliability and convenient maintenance.

The design includes microwave optics, antenna structure, servo control, antenna radiation pattern calculation, etc. Key technological issues lying in the design study are outside the normal experience, and need to be dealt with creativly.

The schematic diagram of the 15 meter antenna is shown in Fig. 2.

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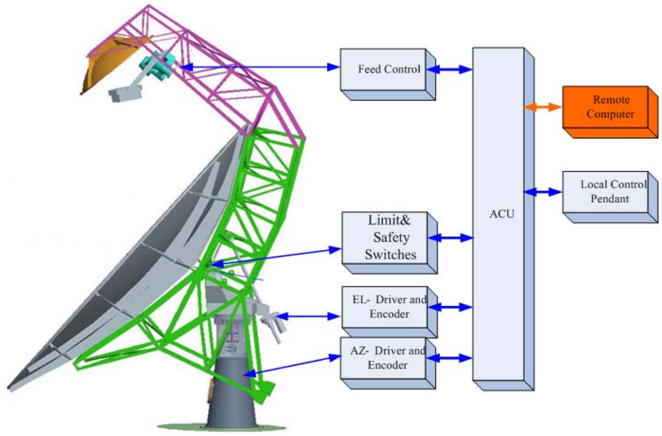

Figure 2. Schematic diagram of DVAC-1.

A. *Microwave optics design*

The microwave optics design includes the design of feed, the shape of main reflector and subreflector.

To cover the frequency range of 0.3-10GHz, two WBSPF feeds are planned. Feed 1 and feed 2 are for ranges of 0.3-1.5GHz and 1.5-10GHz, respectively. The radiation pattern of the feed, and far field pattern of the antenna are simulated [4, 7]. The prototype of feed 1 is shown in Fig. 3.

Dual reflector is shaped to increase the aperture efficiency and lower the first and far-out sidelobes. The shaped optics may also help to obtain a compact structure and minimize the main reflector area. Design parameters are optimized and the results [4, 7] are shown in Fig. 4.

B. *Antenna structure design*

As shown in Fig. 5 the antenna structure consists of the reflector and the mount.

The reflector includes the main reflector, subreflector, backing structure and a feed switch mechanism.

The main reflector adopts an integrated one-piece surface approach, which is benificial for fast installation with less man power. The one-piece panel is partitioned into panel elements as in Fig. 6. The sandwich panel element is made by skin (made of carbon fiber) and foam (made of hard polyurethane), and is shaped by vacuum negative pressure on the mould. The surface accuracy of sandwich panel element is σ≤0.2mm rms [4].

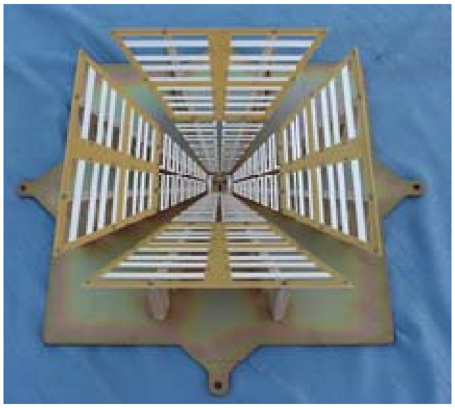

Figure 3. Prototype of WBSPF (feed 1).

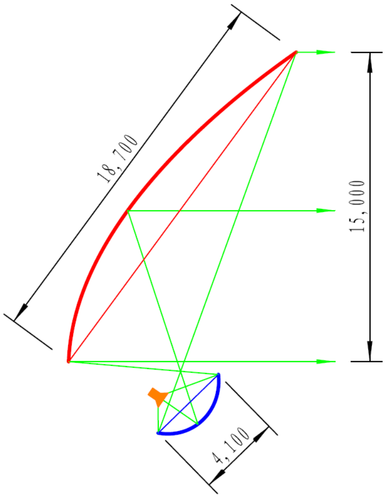

Figure 4. Shaped Offset-Gregorian Antenna

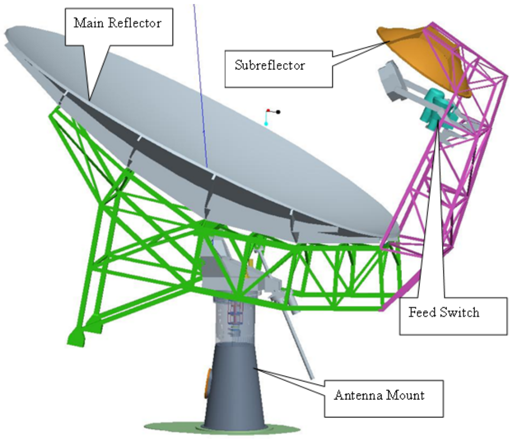

Figure 5. Offset-Gregorian Dish Configuration

On the site, the main reflector is formed by integrating these sandwich panel elements and ribs on a complete mould. Joint methods between different panel elements are shown in Fig. 7. The surface accuracy of the main reflector is σ≤0.6mm rms [4].

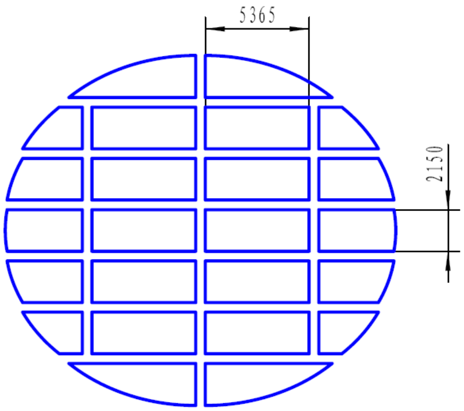

Figure 6. The One-piece Panel Partition.

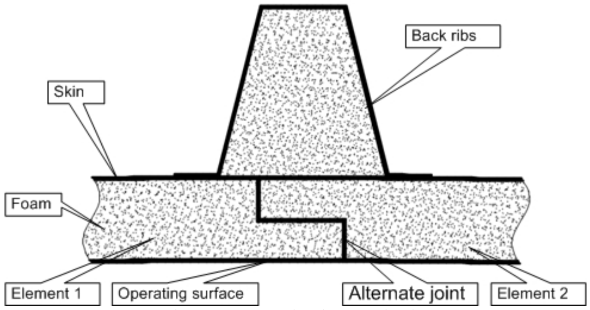

Figure 7. Panel Joint Method

Subreflector is also a one-piece composite foam sandwich structure with metalizing surface, and its reflectivity is higher than 99.5%. The material of skin, sandwich foam and back ribs is as same as that of the main reflector.

The antenna mount is an AZ (Azimuth)-EL (Elevation) type structure, with a gear drive in Azimuth and screw drive in Elevation. The mount has a strong bearing capacity, compact structure and is easy to manufacture and transport.

The total weight of DVAC-1 antenna structure is estimated as 18 300kg, with the reflector 7 050kg and the mount 11 250kg.

C. Antenna servo control system design

The antenna servo control system consists of an Antenna Control Unit (ACU), drivers and motors, power distribution devices, encoders, local control pendant, and a limit and safety protection device, etc. The ACU, drivers and power distribution devices are placed in a RFI-tight cabinet. The block diagram of the antenna control system is shown in Fig. 8.

III. PRIME FOCUS DISH (DVAC-2)

This section presents the conceptual design of DVAC-2, a 15 meter prime focus symmetric antenna with three rotational axis. Its main attractions are similar with DVAC-1, such as the use of WBSPF, integrated modular, one-piece relfector and so on [6].

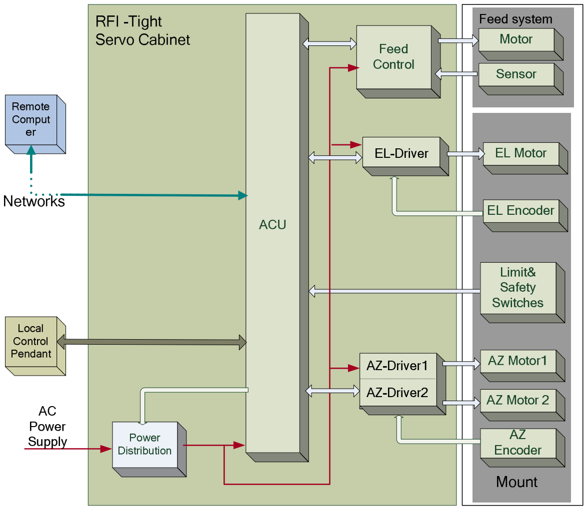

Figure 8. Block diagram of antenna control system.

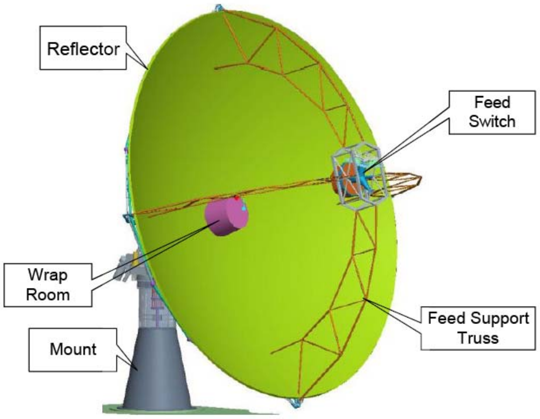

Figure 9. Prime foucs dish configuration.

Configuration of the prime focus dish [6, 8] is shown in Fig. 9. A one-piece reflector is supported by a simple spar structure. The mount has three freedom degrees with an AZ-EL-POL(Plorization) type structure, including a turning head for azimuth, a lead screw for elevation, and a plorization axis as shown in Fig. 10.. A support and interchange mechanism is designed for feeds combination of a PAF and 3 SPFs or 2 WBSPFs.

The reflector also adopts sandwich structure. The skin material can either adopt aluminum or carbon fiber. Total surface accuracy $\sigma \leq 0.8$mm rms [6].

The total weight of DVAC-2 antenna structure is estimated as 19 050kg, with the reflector 6 550kg and the mount 12 500kg.The antenna servo control is similar with that of DVAC-1.

This design has been used on Australian SKA Pathfinder (ASKAP), as shown in Fig. 11. ASKAP is comprised of 36 identical dishes, three-axis prime focus symetric antennas, each 12 metres in diameter. The construction and assembly of the dishes was completed in June 2012. All 36 antennas have been designed and manufactured by Chinese.

Figure 10. Antenna mount structure.

Figure 11. Antenna for ASKAP.

IV. COMPARISON AND FUTURE

Both antenna designs for DVAC-1 and DVAC-2 have their advantages and disadvantages.

The primary focus reflector antenna has the advantage of simpler optics and mechanical structure which are easier to manufacture and at low cost etc. But its shortcomings may include:

(1) It is difficult to simultaneously optimize aperture efficiency and noise temperature;

(2) It has lower efficiency and higher sidelobes due to blockage;

(3) It is mechanically more difficult to accommodate multiple feeds and a PAF at the primary focus.

The advantages of the offset Gregorian reflector antenna are:

(1) Shaped optics may enable high aperture efficiency and low system noise temperature;

(2) No blockage design helps to enhance aperture efficiency and reduce far-out sidelobes;

(3) Feed spillover pointing at the sky can further reduce the system noise temperature;

(4) It is mechanically easier to accommodate multiple feeds at the secondary focus and a PAF at the primary focus.

But its disadvantage is that the asymmetry increases the complexity of the mechanical design and the cost for one single dish. As for mass production of the antennas, the total cost may not increase.

Now offset- Gregorian DVAC-1 is identified as a candidate dish by the SKA and is renamed as DVA-C (Dish Verification Antenna - China). Another two SKA dish candidates are DVA-1 (by Canadan) and MeerKAT (by South African). Studies on these three options are undertaken at the same time. SKADC (SKA Dish Consortium) is formed. SKADC is responsible for the design and verification of dish structure, optics, feed suites, receivers and all supporting systems and infrastructure suitable for SKA in the pre-construction.

Folding in results of the research on the three candidates, the SKADC dish prototype (SKA-P) will be designed and realized by the SKA. Specially points out, no one group or institute will own the SKA-P dish antenna design. SKA-P will integrate advantageous parts of the three candidates from the perspective of system engineering.

The Preliminary Design Review will be held in late 2014. Based on this review, a final optimized antenna may emerge based on the review output.

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