DVA-C: a Chinese Dish Prototype for the Square Kilometre Array

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***Abstract*—The Square Kilometer Array (SKA) has now entered into the pre-construction phase, A hundred of institutes in about 20 countries including China have been involved in its key technology development. The Dish Verification Antenna China (DVA-C) is a prototype being built to farthest meet the requirements from the SKA scientific goals, with unique skin-and-rib structure single-piece panel reflectors. In this paper, design of DVA-C is presented, including optical design, dish structure, and servo. The measured electromagnetic and structural performances, as well as preliminary observational results are provided.**

***Keywords*—Square Kilometre Array; dish; optics; single-piece panel**

I. INTRODUCTION

The Square Kilometre Array [1] (SKA) will be the world's largest radio telescope, providing unparalleled sensitivity and great opportunities for important discoveries and scientific breakthroughs. Given this great ambition for the 21st century, the SKA will meet tremendous challenges in radio astronomy. After two decades efforts, several pathfinders and precursors of different concepts have been built and demonstrated [2-9]. As a co-founder and one of the 10 member countries of the SKA organization, China involves in several work packages in the SKA pre-construction phase. An important contribution to the SKA project is the proposal to realize the Dish Verification Antenna China (DVA-C) [10] and to build the DVA-C.

The DVA-C concept was firstly proposed in the SKA concept design review (CoDR), held in Penticton in Canada in 2011, including an option of offset Gregorian antenna (DVAC-1) and another one of primary focus antenna (DVAC-2). After two years' intensive R&D efforts, the first option exceeds and now DVA-C is focused on an offset Gregorian antenna of 15m diameter aperture with feed-up structure, covering frequencies from 350 MHz up to 20 GHz. The DVA-C antenna adopts single-piece composite reflector technology (although a multi-panel option remains feasible) for main and sub reflectors, El over Az mount, and wideband feeds. Table I shows the specifications of DVA-C, meeting the SKA1 system baseline design [11].

TABLE I. EXPECTED SPECIFICATIONS OF DVA-C.

Items	Specifications
Antenna type	Offset Gregorian, feed-up
Equivalent aperture diameter	15 m
Mount type	EL over AZ mount (AZ：full-motion，EL: Screw)
Reflector structure	Carbon fiber single-piece reflectors
Frequency range	0.35-20 GHz
Aperture efficiency	350 MHz: ~60%, 400 MHz: ~65%, 0.6-8 GHz: ~78%, 8-15 GHz: ~70%, 15-20 GHz: ~65%
Polarization	Dual linear
1st sidelobe	≤ -21 dB
Far-out sidelobe	< -50 dB
Polarization purity	-30 dB (Within HPBW)
Pointing accuracy	≤10 arcsec r.m.s. (Precision) ≤17 arcsec r.m.s. (Standard) ≤180 arcsec r.m.s. (Degradation)
Travel range	AZ：-270°~270°, EL：15°~95°
Slew rates (Max)	AZ：3°/s, EL：1°/s
Acceleration (Max)	AZ：3°/s^2, EL：0.5°/s^2
Ambient temperature	-10℃~55℃
Wind velocity	Drive to stow :70 km/h Survival: 160 km/h (at El=54°)
Lifetime expected	≥30 years

In August 2014, DVA-C was manufactured, integrated and stepped into verification stage (Fig.1), together with another SKA dish prototypes, DVA-1[4] and MeerKAT-1[5].

Fig. 1. Photograph of DVA-C.

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II. OPTICAL DESIGN

To design the DVA-C's optics, a series of offset Gregorian optical options of diverse parameters are set and derived, the corresponding performances were simulated. Then comparisons and tradeoffs were made to best satisfy the specifications. Fig. 2 shows the final optics of DVA-C. Considerations on DVA-C optics down selection are listed below:

- Because the SKA dish will be equipped with several feeds, large feed illumination angle (55°) is selected to reduce the size and weights of feed assemblies.
- An f/D ratio of 0.36 for the main-reflector is selected to make a balance between the space for feed indexer and structure deformation.
- A sub-reflector of 5 m maximum chord is chosen, to improve the aperture efficiency at lower frequency and multi-beam performance with PAFs, while not significantly to increase the fabrication difficulty.
- A feed-up configuration is adopted to reduce the noise due to spillover, the height of the mount, and the weight of dish structure.
- Shaped optics is adopted to achieve the required aperture efficiency.

Reflector shaping is an effective way to realize beam control, such as aperture efficiency improvement, and spillover reduction. Fig. 3 shows the radiation pattern comparison between shaped and unshaped optics at 1.4 GHz, assuming the DVA-C is illuminated by a Gaussian beam of -12 dB edge taper. A 0.4 dB gain improvement is achieved, and the first sidelobe level is lower than -23 dB.

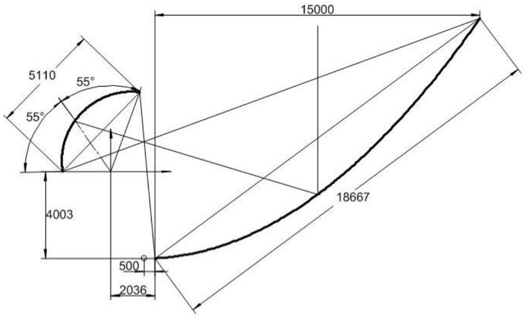

Fig. 2. Geometry parameters of DVA-C.

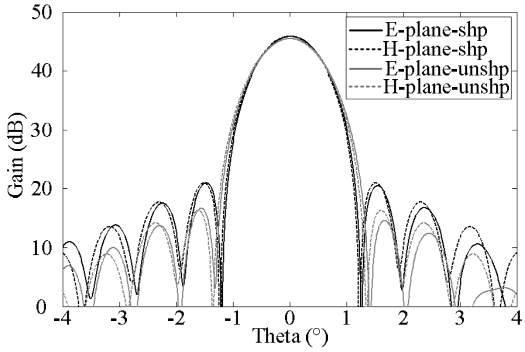

Fig. 3. DVA-C shaped and unshaped pattern comparision at 1.4GHz.

III. STRUCUTE DESIGN

A. Elevation assembly

As shown in Fig.4, DVA-C elevation assembly consists of sub-reflector, main-reflector and steel backup structure. The reflectors are made of carbon fiber reinforced polymer (CFRP).

A novel CFRP skin-and-ribs structure single-piece panel is proposed for DVA-C reflectors. The panel skin of its main-reflector is an integrated and formed carbon fiber layer of 2 mm thickness, coated with aluminum spray. And the backup ribs of composite foam sandwich structure are introduced to enhance the reflector stiffness. As shown in Fig.5, there are seven ribs in horizontal and five in vertical direction respectively. The sub-reflector adopts the same structure, with three backup ribs both in vertical and horizontal directions.

B. Mount

The DVA-C adopts an EL-over-AZ type mount (Fig.6), with a gear drive in azimuth, and a screw drive in elevation. Considering the mass production and maintenance, the modular design is used.

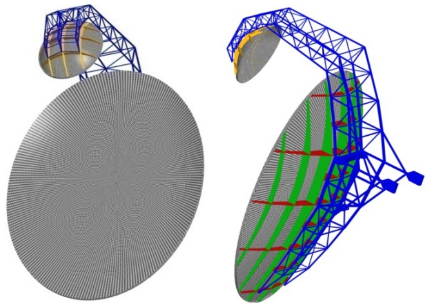

Fig. 4. Drawing of DVA-C elevation assembly.

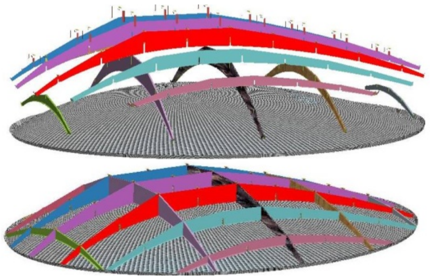

Fig. 5. Main reflector structure diagram.

Fig. 6. 3D model of DVA-C mount.

IV. SERVO

The servo consists of antenna control unit (ACU), antenna drivers and motors, power switch and AC/DC power supplier, encoders, local control pendant, limit and safety sensors, and indexer control unit (ICU), etc. The ACU, Drivers, ICU and AC/DC power supplier are put inside a RFI-tight cabinet. Fig.7 shows the block diagram of the antenna control system.

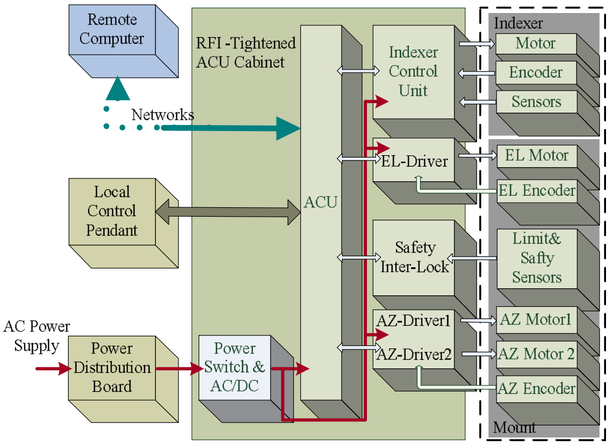

Fig. 7. Block diagram of DVA-C control system.

V. MANUFACTURE

Taking the mass production and fast installation into account, a single-piece panel scheme is preferred by the DVA-C design. The 18m×15m CFRP main-reflector of DVA-C is one of the largest reflector panels in the world. Compared with traditional aluminum material, the CFRP is more practical, with extra advantages of light weight. Fabrication of the single-piece reflector of such large dimension, with required surface accuracy, yields great challenge to the world industry.

Fig. 8 shows the flow chart of the CFRP reflector fabrication. First, the skin and backup ribs are manufactured separately by the VIMP (Vacuum Injection Molding Process). In this way the carbon fiber and resin were polymerized together on the mould, and solidified in specified temperature. Then all parts were joined together by adhesive. At last, the completed reflector is released from the mould. Fig. 9 and 10 show the photos of the VIMP of main reflector skin manufacture and main reflector with some backup structure.

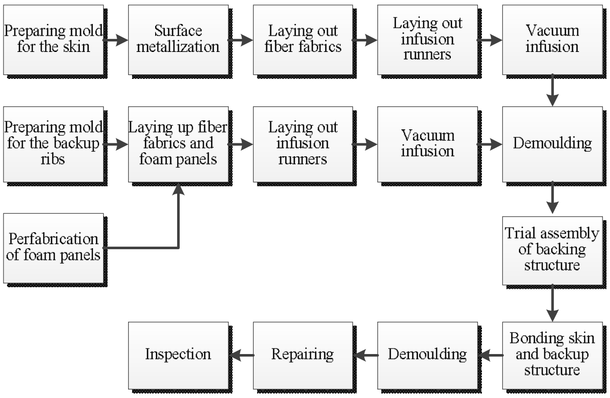

Fig. 8. Flow chart of CFRP reflector fabrication.

Fig. 9. Main-reflector fabrication during the VIMP.

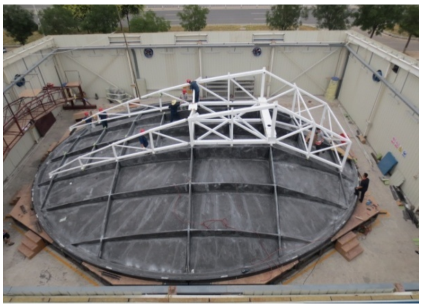

Fig. 10. Main reflector with some backup structure

VI. TEST AND OBSERVATION RESULTS

After the preliminary structural adjustment and servo system debugging, the DVA-C electromagnetic performance was tested. Fig. 11 shows the measured pattern at 3.701GHz. The aperture efficiency is about 78%, with 10.8K noise from sky, atmosphere, and ground.

In December 2014, the first light of DVA-C was well taken. Fig. 12 and Fig. 13 show the observed signals from the neutral hydrogen in the Milky Way and the pulsar B0329+54.

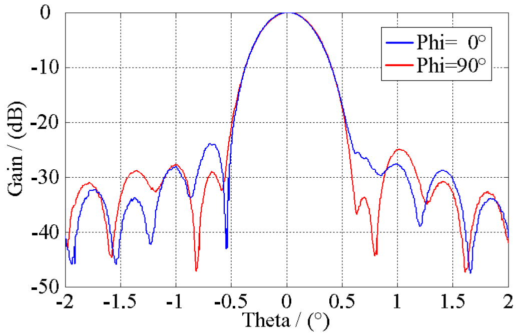

Fig. 11. Tested DVA-C radiation pattern @ C-band.

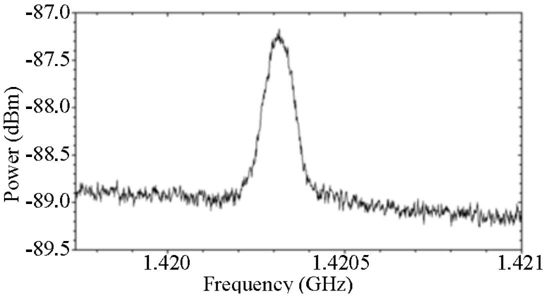

Fig. 12. Neutral hydrogen from our Galaxy.

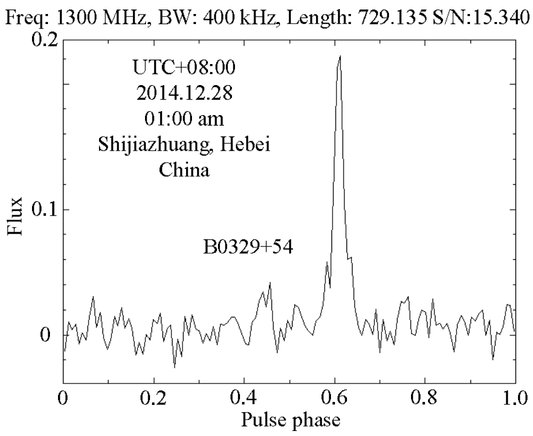

Fig. 13. Test observations from Pulsar B0329+54.

VII. CONCLUSION

The DVA-C is a dish prototype developed for the SKA, aiming at achieving high sensitivity, low cost, and fast installation. Several advanced concepts are introduced in the design, such as high performance wideband feed, CFRP single-piece reflectors, and low wind-load torque pedestal. After one year's effort, the installation of the DVA-C telescope has been completed. Moreover, the DVA-C telescope received the radio signals from the Milky Way and the pulsars. These preliminary results demonstrated that the DVA-C behaves reasonably well as expected, validating the design, manufacture, and installation. All of the work on the DVA-C makes a great contribution to the SKA project, moving the project forward to the next phase.

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