Optical Design of the China Dish Verification Antenna for the Square Kilometre Array

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Abstract

The Dish Verification Antenna China (DVA-C) is a prototype being built to farthest meet the requirements from the Square Kilometre Array scientific goals. In this paper, the details of the optical design of the DVA-C are presented, including the dish optics, and the estimated performance. Although the DVA-C is designed for optimal performance on bore sight, it is potentially employed for phased array feeds. Hence the multi-beam performance of the DVA-C is also analyzed.

1. Introduction

The Square Kilometre Array [1] (SKA) will be the world largest radio telescope, providing unparalleled sensitivity and great opportunities for important discoveries and scientific breakthroughs. Given this great ambition, SKA represents the international challenge in the field of radio astronomy for the 21st century and a worldwide consortium composed of various universities and institutions from more than ten countries has been established. After twenty years development, several pathfinders and precursors of different concepts have been built and demonstrated [2-5], and finally a hybrid concept consists of Low Frequency Aperture Array (LFAA), Dish Array, and Middle Frequency Aperture Array (MFAA, classified as Advanced Instrumentation Program) is adopted. As a founder and main partner of the SKA consortium, China involves in several areas of SKA project and an important contribution of it is the proposal of Dish Verification Antenna China (DVA-C) concept.

The idea of DVA-C was firstly presented in the SKA concept design review (CoDR), held in Penticton, Canada, 2011, including an option of offset Gregorian antenna (DVAC-1) and another of primary focus antenna (DVAC-2). After two years evolution, the first option exceeds and now the DVA-C appears as an offset Gregorian antenna of 15m diameter aperture, feed-up structure, operating from 0.35 GHz to 20 GHz. The DVA-C uses single piece dual reflectors, consisting of 2 mm thick carbon fiber skin and sandwich structure composite backing ribs. An azimuth-over-elevation mount is employed to achieve broad motion range at reasonable cost. In this year, DVA-C will be completed and verified together with another two SKA dish concepts: the DVA-1 from Canada and the DVA-MeerKat from South Africa.

2. DVA-C Optics

According to the SKA baseline design, excellent performance is expected and each part of the dish must be dealt with elaboration. At the starting point of the DVA-C design, a series of offset Gregorian optical options of diverse parameter sets are derived, the corresponding performance were compared and tradeoffs were made to best satisfy the specifications. Figure 1 shows the final optics of the DVA-C. And the considerations in the design are listed below:

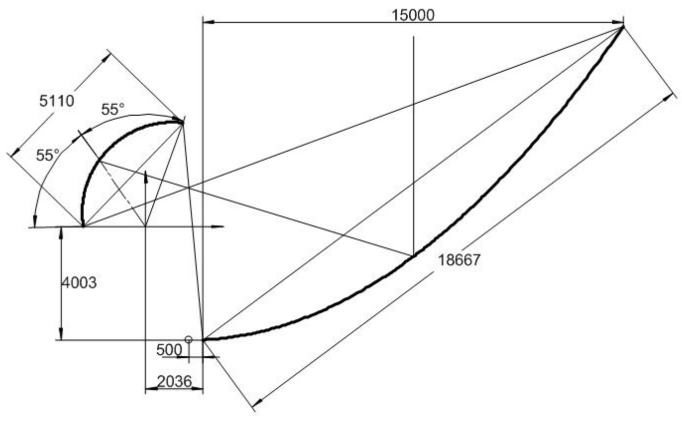

Figure 1. Optics of the DVA-C.

- Since SKA dish will operate with five Single Pixel Feeds (SPFs) or three Phased Array Feeds (PAFs), large feed illumination angle (55°) is selected to reduce the sizes and weights of the feed assemblies.
- A 0.36 f/D ratio of the main-reflector is selected to make a balance between the space for feeds & indexer and structure deformation.

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- The size of the sub-reflector is about 5 m, which is the largest among the three dish concepts, to improve the performance at lower frequency and not significantly increase the difficulty in fabrication.
- A feed-up structure is adopted to decrease the noise due to spillover, and light weight in dish structure.
- Since very high aperture efficiency is required, the reflectors are shaped [6] to fulfill this requirement.

Reflector shaping is an effective way to realized beam control, such as aperture efficiency improvement, spillover reduction, and VSWR minimization of the feed. Figure 2 shows the radiation variance before and after reflector shaping, assuming the sub-reflector is illuminated by a Gaussian beam of -12 dB edge taper. It can be seen there is a rise on the gain with an increment on sidelobes, the aperture efficiency is improved from 73% to higher than 80%. And it can also be found that the pattern becomes more symmetrical after shaping.

A third merit of shaping is shown in Figure 3 that the pattern is less sensitive to illumination edge taper variance. Since SKA dish will employ 5 wideband SPFs, and possibly the ultra-wide band feeds like quad-ridge flare horn (QRFH), the variance in illumination is inevitable. And the simulation result indicates that as the illumination edge taper changes from -10db to -20 dB, the gain and 1st sidelobe of shaped optics are more stable.

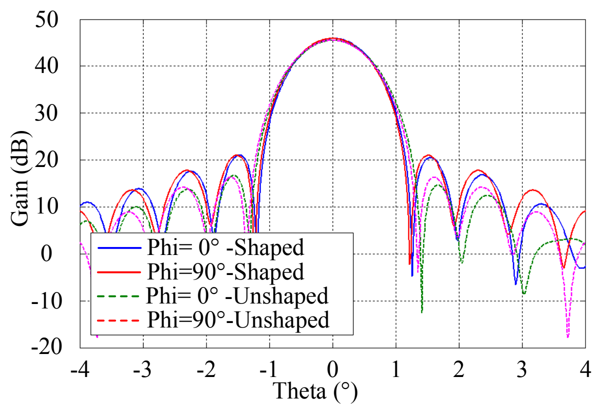


Figure 2. The simulated DVA-C pattern at 1.4GHz.

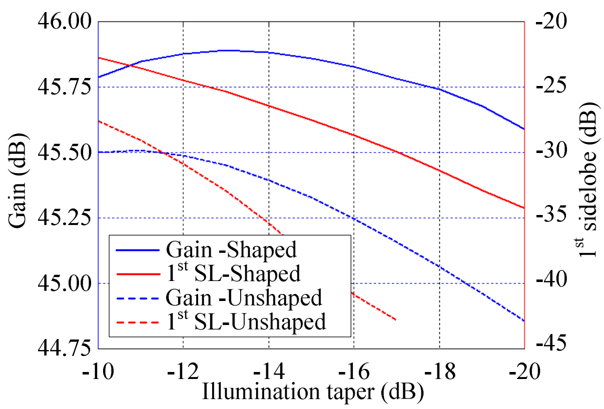


Figure 3. The pattern variance with the edge taper.

3. Estimated Performance with Single Pixel Feeds

At least three SPFs will be tested on the DVA-C, corresponding to the Band 1, Band 4, and Band 5 defined by the SKA. And a forth position is reserved for the Band 2 feed assembly, for the planed verification. Based on the operating bands, three distinct feeds are designed and being fabricated: the Eleven feed for Band 1, the corrugated horn for Band 4, and the QRFH for Band 5. Table 1 lists the estimated performance of the DVA-C over the operating band, using realizable feeds and 0.5mm r.m.s. surface error.

Table 1. The estimated performance of the DVA-C.

Band	Frequency (GHz)	1st sidelobe (dB)	Aperture efficiency (%)
1	0.3	-20.87	69.95
	0.6	-25.17	77.14
	1.05	-29.25	74.73
2	0.95	-24.64	79.23
	1.76	-27.78	78.69
3	1.65	-25.18	80.63
	3.05	-28.82	79.40
4	2.8	-25.53	81.47
	5.18	-28.64	79.67
5	4.6	-25.27	82.15
	9.2	-28.03	78.67
	13.8	-34.04	70.44

4. Considerations on PAFs

The PAF is an emerging technology for radio telescopes, offering the potential for wide continuum field-of-view (FoV) and fast sky survey. Compared with traditional cluster horns, PAFs provide much more closely overlapped beams with flexible performance and the capability of RFI mitigation. These merits will endow telescope with enhanced observing ability and open up new science [7]. Since it is preferred that the same optics should be used for SPFs and PAFs in the SKA, the effect of the DVA-C shaped optics on multi-beam performance needs to be investigated.

As shown in Figure 4, one principal change of shaped dual reflector antennas is that there will be no primary focal point, instead a caustic region. The primary focal field variance is shown in Figure 5, assuming the plane wave incident in the azimuth/elevation planes at 1° interval at 1.25GHz.

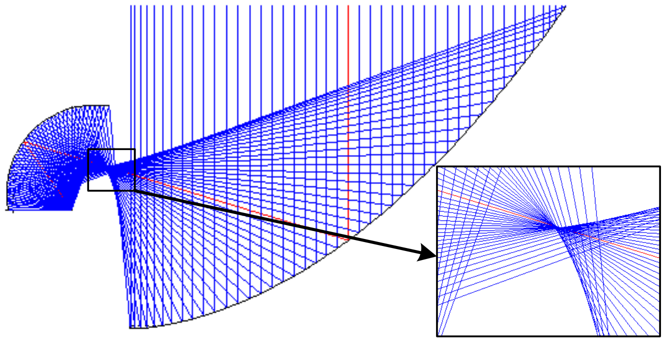
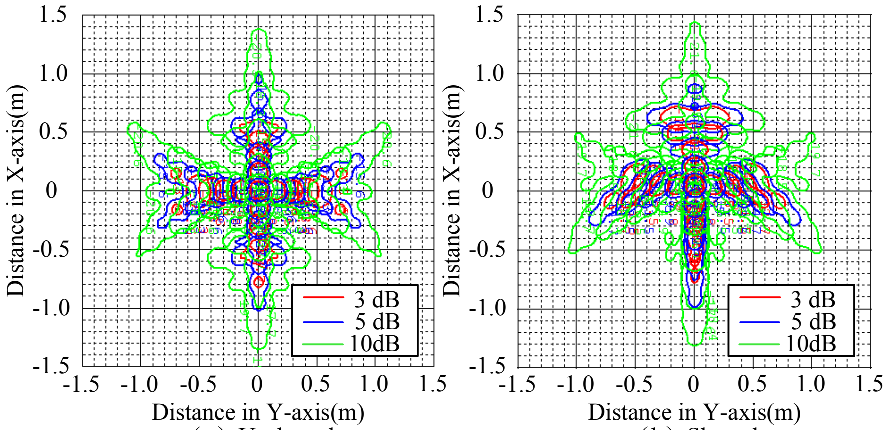


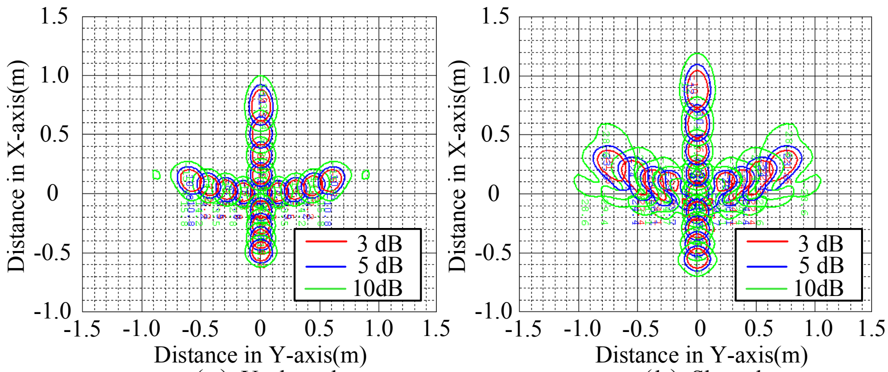
Figure 4. The optical path of the DVA-C.



（a）Unshaped （b）Shaped

Figure 5 The field distribution variance at primary focus due to reflector shaping.

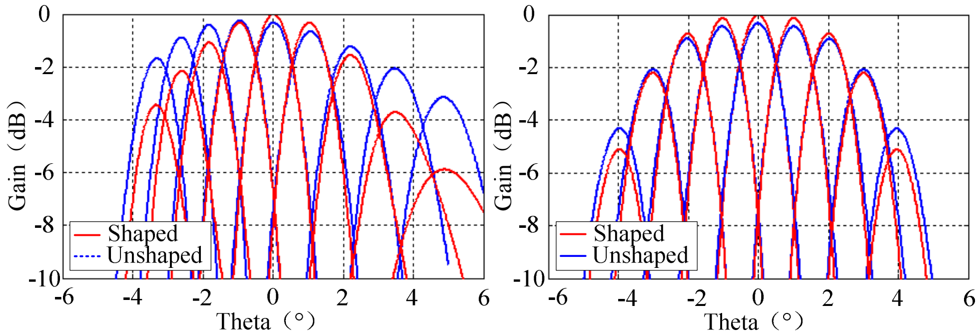
Figure 6 shows the secondary focal field with the same excitations as Figure 5. The caustic also happen, indicating that a larger array is needed to achieve the same field of view as unshaped optics. However, the field distribution area is relatively smaller than that at the primary focus, indicating that a smaller array is needed here.



（a）Unshaped （b）Shaped

Figure 6. The field distribution variance at the secondary focus due to reflector shaping.

Compared with the previous option, placing the PAFs at the second focus introduces an additional loss from the leakage at the sub-reflector edge. And this effect deteriorates as the incident wave incline from the bore sight. `As shown in Figure 7, reflector shaping provides significant gain improvement on bore sight and near. However, the modified optics results in more fast performance degradation when the beam steers. And the degradation is more serious in elevation plane than azimuth plane. This result is based on SPF at 1.25 GHz. Fortunately the PAFs can compensate the shaping effect via proper beam-formers, and performance degradation will not be that large in Figure 7.



(a). Elevation plane **(b) Azimuth Plane**

Figure 7. The gain degradation with the beam steer away from bore sight.

5. Conclusion

The details of the DVA-C optical design are presented in this paper. A shaped optics is selected to achieve excellent performance for SPFs. However, the reflector shaping brings trouble to PAFs and more studies will be carried out to investigate this effect in the future.

6. Acknowledgments

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7. References

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