

The optics of the Five-hundred-meter Aperture Spherical radio Telescope

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Abstract- In this paper, we give a brief description of the evolution of the optics of FAST telescope. Several milestones that lead to the current FAST concept are presented. These include the lightweight focus suspension, active main reflector, backward illumination and new feed technology such as Phase Array Feed, etc. A perspective for future development is given in the end.

I. INTRODUCTION

FAST is the currently largest single dish radio telescope that has been proposed. The project was approved by the Chinese National Development and Reform Commission in 2007. The construction was officially started in March 2011, and will be completed in September 2016 [1] [2].

There are mainly three innovative features of FAST telescope [3]. The telescope is built in a nearly spherical Karst depression in Guizhou province. The second is the active main reflector. The neutral shape of the main reflector is spherical. The illuminated part is deformed into a paraboloid of revolution [4]. The last is the light focus cabin suspension system, which enables the positioning of the feed with an accuracy of less than 10mm [5].

A brief description of the evolution of the optics of FAST will be presented in this paper. In the next section, several milestones of the formation of the FAST concept are reviewed. The current optics of FAST is described in the third section. A concluding remark is made in the end.

II. MILESTONES OF THE CONCEPT FORMATION

FAST telescope is originated from the Chinese SKA (LT in early days) effort. Chinese astronomer proposed an array of 20-30 Arecibo-type telescopes to obtain a collecting area of one square kilometer. And we did a comprehensive site survey of Karst depressions in the Guizhou province in Southwest part of China. Several hundred depressions have been found to be proper site candidates to accommodate large spherical radio telescope.

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FAST, as a single dish, was proposed as a pathfinder of the Chinese SKA concept. Feasibility study has been carried out to tackle the technical challenges of building Arecibo-like telescope. In spite of the researches about the structure, measurement/control and receivers, the optics also underwent substantial evolutions. Here we list and describe the most significant milestones of this evolution.

A. Spherical main reflector and light weight feed suspension system

Since it is very difficult to realize a fully steerable telescope with a diameter of 200-300m, an Arecibo-like spherical surface seems was a natural choice. In the early days of Arecibo, long line-feed was used to illuminate part of the main reflector. However, the very narrow band line-feed is not suitable for a general purpose radio telescope.

Hybrid feed was proposed to illuminate a spherical radio telescope[6]. A lightweight feed suspension system was also contemplated [7]. Like Arecibo, there is no rigid connection between the feed and the main reflector. But this suspension mechanism use six cable to position the feed, thus eliminate the very large up-side-down AZ-EL feed platform as appeared at Arecibo.

The early FAST technical scheme was featured by a very large spherical main reflector and a light feed suspension system [5].

B. Active main reflector

An active main reflector was proposed to correct the spherical aberration on the ground [4]. After a proper f/D is chosen, a minimal radial deviation of a spherical surface with a paraboloid of revolution could be obtained. The main reflector is then segmented into some 1100 hexagons of 10-m edge. If a point-feed is put at the focus point, the illuminated aperture of 300m diameter is deformed into a paraboloid of revolution in real-time. This scheme is somewhat different from the active surface adopted at other large radio telescope, such as GBT, LMT and the newly built 65m radio telescope near Shanghai in China, which is used to compensate gravitational and thermal deformations when the telescope is pointing different points on the sky.

This active main reflector scheme allows highly-advanced point feed to be adopted for FAST. And since the elementary panels stays approximately at the same tilting angle during observation, thus the gain remains almost constant when tracking a source.

Two main schemes were proposed to support the thousands of panels. One is rigid structures consist of concrete pillars, and actuators were used to push the panels from underneath. Down scale model experiments has been carried out to demonstrate the feasibility. Self-adaptive mounting of the panels was also proposed during the research. Another scheme is to use cable network and downlink cables to form a virtual “back structure” to support the panels. In this scheme, the elasticity of the cables is used to realize the deformation, and the driving mechanism is on the ground which makes maintenance more easier.

The cable network is chosen to be the final technical scheme for active main reflector for FAST. Studies have been carried out to address key technical issues such as the type of driving mechanism, material selection for the cables and self-adaptive mounting of panels, etc.

C. Focus suspension system (with Stewart platform)

Simulation study of the original focus cabin suspension system for the line feed using six cables shows inadequate accuracy for positioning the point feed at higher frequencies. Stewart platform was introduced to compensate the residual positional errors caused by wind and the inherent vibration of the cable suspension system [8]. A X-Y rotation mechanism was also introduced to get the orientation of the Stewart platform roughly correct.

In order to achieve satisfactory position accuracy of the lower platform, it is suggested that the ratio of the mass between upper and lower platform should be no less than about 10:1. During the same period, a set of receiver was proposed by a joint study of NAOC and JBO in the UK. Though the backend changes dramatically during the last decade, the frontend technology didn't change very much. So the 2-3 tons weight of the feeds and low noise frontend to be mounted on the lower platform remains effective.

D. Zenith angle and “backward illumination”

Compared with the Arecibo telescope, which remained the largest radio telescope since the completion of it's construction, has a zenith angle limit of about 20 degrees. FAST has larger zenith angle coverage. The reason is as follows:

First, the spherical surface of FAST is deeper, which allows the main reflector to collect radiation from lower elevations.

Second, FAST adopted a cable-driven focus cabin suspension system. This system is much flexible compared with the large triangular platform. I.e. the zenith angle is mainly limited by the ability of the focus cabin suspension system. Larger zenith angle could be achieved if more power is available or a lighter focus cabin is used.

When the zenith angle is larger than ~ 26.4 degree, the illuminated 300m aperture will go beyond the edge of the 500m spherical surface. As the zenith angle continues to become larger, the feed will see more noise from the

surroundings. A ground screen made from wire mesh was proposed to block the noise from the ground. In order to achieve zenith angle of 40 degree, this ground screen would need to be some 45m high. This one mile long and 45m high ground screen would then become a noticeable infrastructure by itself.

An offset illumination was considered for the above situation. When the illuminated 300m aperture exceed the edge of the spherical surface, the feed will be rotated about it's phase center backward towards the center of the 500m aperture. This “backward illumination” will eliminate the need of a ground screen since the feed will see the un-deformed surface on the other side instead of the warm ground out of the edge. Simulation has shown that the on-axis gain under the “backward illumination” mode differs very little compared with the normal mode where a ground screen is adopted.

E. New feed technology: Phased Array Feed and line feed to illuminate the whole reflector

New feeding technologies have been investigated during the last decade for FAST telescope. These include Phase Array Feed (PAF) and long line feed. Though this is not a milestone yet, when the technology is ready, it will enhance the ability of FAST telescope enormously.

FAST would be a powerful instrument for pulsar and HI survey, the current 19-horn receiver provides 19 simultaneous beams on the sky. Same horns are used for all the beams, and the off axis beam will have lower gain and worse far field pattern. And the beams on the sky have gaps since apertures of the adjacent feeds can not overlap. The PAF occupies the same area of the focal plane may be able to provide continuous sky coverage, and the far field patterns for each beam may essentially be the same, with on-axial gain higher than that obtained by using horns. The PAF may provide more advantages compared with using horns [9].

When joining the current international VLBI network, FAST will greatly increase the baseline sensitivity, thus allow more weaker sources to be observed. The PAF will enable FAST to have comparable FoV as smaller telescope, thus allow specific observation modes (such as in-beam phase referencing) to be carried out.

If we used a 140m long line feed, we may be able to effectively illuminate the whole 500m spherical aperture. By putting wideband elements along the line, and compensating the different relative time delay of the signals from the various elements digitally, a wideband line feed may be realized. Though the sky coverage is limited to a stripe on the sky, it may become a quarter of SKA in terms of collecting area.

III. OPTICS OF FAST

Based on the above description, FAST can be seen as a prime focus paraboloid radio telescope with zenith angle limit of 40 degrees. But FAST has it's own specific characters, e.g. the gain remains almost constant for different elevation angles,

the metal panels out of the illuminated area will reduce the noise due to feed spillover.

IV. CONCLUDING REMARKS

FAST is an unusual telescope. Compared with Arecibo, the current largest single dish radio telescope, FAST is featured by its active main reflector and delicate lightweight focus suspension system, but this simplicity and delicacy in structure dictates much more difficulty and challenges in the measurement and control of all the parts to work in a coherent manner (private communication with Donald Campbell, the former director of Arecibo).

The main reflector of FAST could be deformed into any shape between a sphere and a paraboloid, this flexibility may allow various optics to be investigated. The shape of the panel will give a limit of the highest frequency end. Improvement of the focus cabin suspension and dynamic beam forming using PAF may help to reach this high frequency limit.

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