The Universe at Low Radio Frequencies
IAU Symposium, Vol. 199, 2002
A. Pramesh Rao, G. Swarup and Gopal-Krishna, eds.

The Development of the FAST Project in China

R. Nan, B. Peng, Y. Qiu, L. Zhu, Y. Su and W. Zhu

Beijing Astronomical Observatory, NAOCAS, Beijing 100012, China

Abstract. Acting as a pilot of the Square Kilometer Array (SKA), the Five hundred meter Aperture Spherical Telescope (FAST) has been proposed for construction in the unique karst area of southwest China. FAST is of Arecibo-type with rather a number of innovations, among which the active main spherical reflector shows fascinating. Furthermore, the feed cabin is supported and moved by cables controlled by computer, which avoids a heavy and expensive focal pointing system. With the effective aperture of 300 m, a large sky coverage, and a broad bandwidth (200 to 2000 MHz), possible capability up to 5 ~8 GHz, FAST will be the world's largest single dish and perform markedly role in radio astronomy.

1. The concept of FAST

One way to realize the SKA is to construct a spherical reflector array of about 30 individual unit telescopes, each roughly 200m diameter. FAST has become one of the key projects in the Chinese Academy of Sciences. The goal is to have the FAST decided as a National Mega-Science Project of China in 2001, and to build it by ~4 years in southwest China with an estimated cost of 40 M $US\$$.

The FAST is not simply a copy of the existing Arecibo telescope but has rather a number of innovations. The practical way to build it is to make extensive use of existing depressions which are usually found in karst region. Since early 1994, site survey started in the south of Guizhou province of China (latitude 26°N, longitude 106°E). At least 400 depressions were investigated with the Remote Sensing and the Geographical Information System, and selected as the candidates for site locations. More than ten depressions were imaged at a high resolution of 5 $m/pixel$, showing suitable profiles for large spherical reflector[1]. Due to the remotness of this region and local terrain shielding of karst hills, preliminary results of radio interference monitoring are quite promising[2].

The optical geometry and 3-D computer image of the FAST are shown in Fig.1. Main reflector is a spherical cap with a radius of ~300 m and an opening up to 500 m in diameter. The effective aperture of 300 m is illuminated by the feed which moves on the focus surface in the half way from the reflector to its center. The telescope is "pointed" by moving the feed cabin, and by simultaneously adjusting the shape of the illuminated surface. The geometrical configuration combined with the offset illumination by rotating the feed backwards as it is forwarding to the edge of the reflector will enable FAST to have larger zenith angle up to 60° compared with Arecibo telescope. Shorter wavelength up to 8 GHz has also been suggested depending upon the cost.

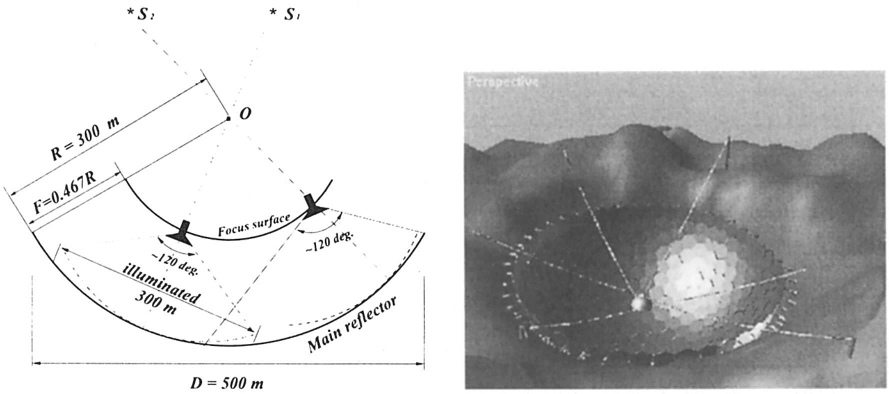

Figure 1. Optical geometry(left) and 3-D computer image(right)

Figure 2. The FAST main reflector is composed of ~1800 hexagons.

2. Active main reflector

During tracking the object, the illuminated part of the main spherical reflector is to be continuously adjusted to fit a paraboloid of revolution in real time by active control. It is known that the central part of a spherical surface deviates little from a paraboloid of revolution as a proper focal length is chosen, based on which, a novel design for a spherical reflectors is proposed [3]. If the focal length is set to be 0.467R (~140 m) in the configuration shown in Fig. 1, the peak of the deviation will be minimized as 0.67 m within the illuminated aperture. For the maximum apparent motion of the celestial objects, the rate of variation is found to be less than 5 $cm \cdot min^{-1}$, which enables inexpensive solution for mechanical control. This attempt breaks the bandwidth limit due to spherical aberration without involving complex optical corrections in feeding system.

To deform the main reflector surface, it is necessary to divide it into small elements. Each element is a small part of the spherical surface and its curvature should be optimized to get the best fit to the paraboloid. Fig.2 shows one of the segmentation methods. Firstly, the segmentation has been done in a flat plate which is divided into ~1800 indentical hexagons with side 7.5 m long. Secondly, sink the plate onto the spherical cap, keeping the length along the radial direction unchanged. Whereas, the dimension of the hexagoon along the altitude directon is shorten by a factor cos(θ), i.e.,$Lc = L * cos(\theta)$(see Fig.2). Each element has three actuators to fix its position and connect it with adjacent elements, and there would be an average of one actuator per element. As the telescope is tracking and forming a real-time parabola, the actuators move along the radial direction with a throw of 67 *cm* and rate of 4.4 $cm \cdot min^{-1}$ in maxima.

Errors of the reflector surface will have three components: (a) dominant error component due to the deviation of the spherical shaped element from an exact parabolic one, (b) actuator settings, and (c) smaller scale irregularities including deviations of the flat panels composing the element from parabolic shape, manufacturing, etc. Assuming these errors to be random in nature(it is not true for the case(a)), the efficiency of the reflector could be estimated by the Ruze formula. If the r.m.s of the aperture is expected to be smaller than $\lambda/16$ (~4 *mm*) at 5 *GHz*, then the largest dimension of each element in Fig.2 should not exceed 15 *m*. Obviously, smaller elements are advantageous to make more accurate fitting and therefore increase the radio metric efficiency of the antenna. However, this will be contrary to the most critical aspect of the design of the reflector – an inexpensive supplementation and its reliability. The gravitational and thermal deflection on the structure, the possible interruption between elements, the gaps on the reflector and their effect on antenna gain and beam pattern, and many other aspects require further investigation by computer simulation and test on physical model.

3. Cable supporting platform and pointing

The weight of a similar feed platform as the Arecibo antenna for FAST would be estimated as ~10,000 *tons* considering the large opening and depth of the reflector. An innovated design integrating mechanical, electronic and optic technologies has been intensively investigated since 1995 [4].

The whole system consists of three parts (see Fig.1). Firstly, there are six suspended cables driven by servo-mechanism which move the focus cabin of 20~30 *tons* on the focus surface, keeping the position within an error volume. Detailed analysis of the system statics and kenimatics proved the feasibility of positioning and tilting the cabin by changing the length of cables. Non-linear analysis of the dynamic behaves of the structure has predicted the maximum magnitude of the oscillation as 50 *cm* and its frequency lower than 0.2 *Hz* under wind load. The input data are based on Davenports Spectrum of wind speed supplemented by actual value collected near the candidate sites. The system will be much more stable if Tuning Mass Damping technique is applied to the system. Secondly, there must be a stabilizer mounted by a group of pre-amplifier with feed (or multi-beam feed) in the cabin. The errors of the 3-D focal position can be decomposed in those components: (1) Linear displacement ΔS on the focal plane, whole maximum allowed value is determined by $F \cdot \theta/10$, where F is the focal length, θ is beamwidth. At the highest frequency, ΔS requires to be controlled under 4 *mm*. (2) The linear movement along the direction of ray path (normal to the focal plane). This component mainly effects antenna gain, 4 *mm* cause a gain loss much less than 1%. (3) Rotation of phase center, 1° offset decreases antenna gain by 0.4% and changes the beam direction by a negligible value $6 \times 10^{-6} arcsec$. However, (3) is not an independent component, it will generate (1) and (2) for multi-beam feed. Hopefully, there is a device available for this second adjustable system with a final goal of 4 *mm* accuracy – Stewart

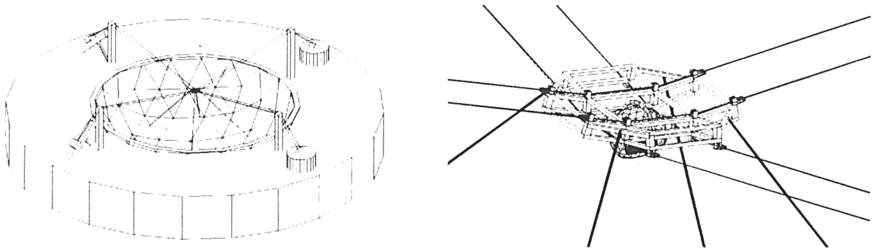

Figure 3. A alternative kind of cable supporting system, which is somehow like a trolley on the cable-way.

platform manipulator which starts to be utilized by machine work nowadays. At the last, accurate measurement and control system as the third critical part is necessary to read the position of feed in real time, feedback the information to the central computer and realize a global looped control. Another kind of cable supporting system has also been detailed studied (Fig.3, Ren et al., in prep.). Positioning the focus cabin can be achieved by driving the car on two cross sets of upward cable, which is somehow like a trolley on the cable-way in mountains. Rotating and tilting the cabin are going to be realized by some bearings mounted on the car. In addition, there are four downward cables fastened to four anchors to prestress the structure. This application will reduce the maximum length of cable change by factor 10 at least, moreover, may great improve the dynamic characteristics of the system.

Besides above two, other alternative schemes for this most critical component of the FAST were also proposed. Considering the huge volume in which the moving feeds will be accurately positioned and acceptable budget of construction, none of those efforts adopts standard antenna design, instead, high technology solutions. Feasibility work of the cable supporting platform has already given preliminary results. Prototyping and testing are required, and designing a scaled physical model has started now.

The FAST will be especially effective in deep surveys for sources such as rare types of pulsars and netural hydrogen clouds at moderately high redshifts. FAST as a VLBI station will be the hub of the most highly sensitive network. FAST will play an important role in the deep space network, and in SETI searches.

References

R. Nan, et al., 1996, in Proc. of the LTWG-3 & W-SRT, eds: R.G. Strom, B. Peng, R. Nan.

B. Peng, et al., 1996, in Proc. of the LTWG-3 & W-SRT, eds: R.G. Strom, B. Peng, R. Nan.

Y. Qiu, 1998, MNRAS, 301, 827.

B. Duan, et al., 1996, eds: R.G. Strom, B. Peng, R. Nan.