Preparatory Study for Constructing FAST, the World’s Largest Single Dish

By Bo Peng, Chengjin Jin, Qiming Wang, Lichun Zhu, Wenbai Zhu, Haiyan Zhang, and Rendong Nan

ABSTRACT | A 500-m aperture spherical telescope (FAST) was funded by the National Development and Reform Commission of China (NDRC) in July 2007 and will be located in the unique Karst region, a sinkhole-like landform, in Guizhou province. FAST can be seen as a modified “Arecibo” type radio telescope using many innovative techniques, with as much as twice the collecting area and a wider sky coverage. FAST has, first, an active reflector, conforming to a paraboloid of revolution from a sphere in real time through actuated control, which enables the realization of wide bandwidth and full polarization capability by using standard feed design. Secondly, it has a light focus cabin suspension system, integrating optical, mechanical, and electronic technologies, reducing effectively the cost of the support structure and control system. With such a huge collecting area of more than 30 football fields, FAST will become the largest single dish ever built. Here we will summarize the FAST concept and the milestones achieved in experiments on its key technologies, i.e., site exploration, active reflector prototyping, focus cabin driving mechanism, measurement and control techniques, and the receiver layout. The Miyun FAST demonstrator also will be presented.

KEYWORDS | Active reflector; focus cabin driven by cables; Karst depression; prototyping; spherical telescope

I. INTRODUCTION

In the early 1990s, a large radio telescope, called the LT (SKA after 1999), was proposed by astronomers from ten countries including China at the 24th General Assembly of URSI. It was to be an array with a collecting area of about one square kilometer, to receive radio signals from the distant early universe.

Chinese astronomers proposed building a large spherical reflector array in 1994 by making use of extensive karst landforms, which are bowl-shaped limestone sinkholes. The effort is referred as the Kilometre square Area Radio Synthesis Telescope (KARST) approach, composed of 30 individual elements each 200 m in diameter. After three years of brainstorming and paperwork, the 500-m aperture spherical telescope (FAST) concept was born as a forerunner of the KARST project. Preliminary research on the FAST project was carried out successfully as one of the pioneering Innovative Projects of the Chinese Academy of Sciences (CAS) from 1999 to 2001, followed by an extensive feasibility study on critical technologies as well as assembly of a FAST demonstrator at Miyun radio astronomical observatory, which was funded jointly by the CAS and the National Natural Science Foundation of China. We are currently optimizing the layout design, testing most of the key component engineering details, and preparing to start construction at the FAST home, Dawodang depression at Pingtang county, Guizhou, for 2009. Undoubtedly, FAST will produce outstanding scientific discoveries in its own right.

II. CONCEPT

The optical geometry of FAST is shown in Fig. 1(a), where the huge reflector is a spherical cap with a radius of \( R \sim 300 \text{ m} \).
and an aperture of 500 m in diameter. Its opening angle will be \( \sim 120^\circ \). The effective aperture of \( \sim 300 \) m is to be illuminated by the feed in a cabin moving on the focus surface of 206 m in diameter, halfway from the reflector to its spherical center. Such a geometrical configuration enables the FAST to have a larger sky coverage (\( \sim 40^\circ \) zenith angle) than the Arecibo telescope (\( \sim 20^\circ \) zenith angle). The receivers will cover a frequency range between 70 and 3000 MHz, with capability up to 8 GHz for future upgrading. In particular, a 19-beam receiver at L-band will be mounted in the focus cabin. The sensitivity in terms of \( A/T \) (the ratio between the effective collecting area (A) and the system temperature (T) of the telescope) should be \( \sim 2000 \) m\(^2\)/K at L-band. The FAST will, as a single dish, have the largest collecting area in the world.

The telescope is pointed by moving the focus cabin and adjusting simultaneously the shape of the illuminated reflector from a sphere to a paraboloid, as shown in Fig. 1(b). FAST will be more than twice as large as the Arecibo radio telescope. Technically, FAST is not simply a copy of the existing Arecibo telescope but has rather a number of innovations, such as a huge spherical reflector, actively actuated to conform to a parabolic shape, and a light feed support to be driven by cables and a servomechanism, plus a parallel robot as a secondary adjustable system to precisely position the feeds.

The innovative engineering concept and its design are a new road to constructing a huge single dish. Being the most sensitive radio telescope, FAST will offer astronomers a chance to make great scientific discoveries by, for example, neutral hydrogen line surveys at distant galaxies out to high red-shift, looking for the first shining stars, detecting some thousands of new pulsars, exposing exotic objects, becoming the new host of a very long baseline interferometry (VLBI) network, etc. It should be also noted that almost all of the outstanding astronomical discoveries could not have been anticipated at the time that a telescope was being planned.

FAST will also help other research to flourish, for instance, in space weather studies and deep space exploration. The construction of FAST itself is expected to promote further development in relevant high technologies.

III. SITE EXPLORATION

Guizhou province is located on the inclined region from the Yunnan-Guizhou Plateau to the Hunan Hills. The topography declines from high to low going from west to east. Sedimentary rocks account for more than 85% of the area of Guizhou. Historical data show that there have been more than 250 earthquakes in the past 700 years, of which eight had magnitude higher than 5.0 and the rest were lower than 3.0. Guizhou is one of the provinces with better seismic stability, providing largely karst depressions to house FAST and SKA. A comprehensive evaluation of the engineering and hydrological geologies, meteorology, electromagnetic environment, natural resources, and social development has been conducted. Among the many factors affecting the selection of a site for constructing a radio telescope, the ambient radio-frequency interference (RFI) environment is particularly critical.

A. Geological Conditions

Karst depressions naturally form in special limestone areas. There are more than 760 karst depressions concentrated in southern Guizhou, extending for about 500 km toward eastern Yunnan Province. A large number of karst depressions, at least 300 in Pingtang and Puding counties, were investigated with remote sensing, geographical information system, and on-the-spot observations in the past decade, and selected as candidates for the potential SKA site. More than ten depressions were imaged at a high resolution of 5 m/pixel, showing suitable profiles for large spherical reflectors.
Dawodang depression is a close peak-cluster depression of five large surrounding peaks. The peak located in the ENE direction away from the depression is the highest in elevation, 1193.8 m. The bottom elevation is 841.2 m. The shape of the topographical section of Dawodang depression in Fig. 2(a) looks like the letter “U” with a diameter of about 800 m. The low center of the depression is like a caldron and is used as arid land. Its upper segment is steep and is used as woodland. No geological hazards (landslide, collapse) have been found in the depression. Some mapping details are illustrated in satellite, digital earth model three-dimensional (3-D) images in Fig. 2(b) and (c). Site investigation by a resistance measuring technique and drilling experiments is presented in Fig. 3, exploring the hydrogeology and engineering geology conditions underground. Dawodang depression, having a round shape and stable geology without inundation risk, has been selected as the most ideal home for FAST, also from the radio quiet point of view, as addressed in the following section.

B. RFI Investigation

A series of RFI measurements were initiated with a portable equipment from 1994 at some potential SKA locations in Guizhou province and an additional one at Urumqi Astronomical Observatory in Xinjiang Autonomous Region, China, providing a snapshot of the situation in terms of spectrum, strength, and temporal characteristics of the radio interfering signals to check on their suitability from the point of view of RFI. The early RFI monitoring sessions consisted of measurements at eight karst depressions for ten days in November 1994, and additional ones including half of the above sites in March 1995 for about a month and intermittently until 2000, covering the frequency range of 50–2000 MHz, in an attempt to understand distance and time evolution effects. The results showed that the radio environment was statistically stable [8], [9].

Since December 2003, an RFI measurement campaign has been conducted continuously for more than a year, to acquire data on background levels at potential SKA sites by

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**Fig. 2.** Topographical section of (a) Dawodang depression showing suitable profiles for hosting spherical reflectors and (b) the Quickbird satellite where the circle gives a 1 km scale. (c) 3-D images.

**Fig. 3.** Site explorations: (a) resistance measurements, where the y-axis shows the altitude above sea level and the x-axis the horizontal dimension across, both in meters. (b) Investigation by drilling at Dawodang depression.
focusing on transmissions from directions around the horizon [10]. During July 3–29, 2005, an international SKA measurement team carried out calibration measurements at Dawodang, enabling cross-calibration with the Chinese RFI monitoring system. The RFI observations were divided into two modes: a survey of strong RFI potentially causing saturation and thus nonlinearity, which is referred to as a mode 1 measurement, and that of weak RFI, which obscures signals of interest, which is designated mode 2. The basic monitoring system consists of a spectrum analyzer FSP-30, antennas, corresponding low-noise amplifiers, turntable antenna mounts, and a control computer with special software for the RFI measurements.

In the frequency range 70–1000 MHz, the HL023 and HL033 model log-periodic antennas were used for vertical and horizontal polarizations; for 1000 MHz to 22 GHz, the HL050 model antenna was used. In the process of making the measurement, the noise source was switched on and off to calibrate and check the performance of the system after each monitoring task. The monitoring data were finally converted to flux density spectra that are expressed in decibels $S = 10 \log_{10} \left( \frac{E}{Bw} \right)$, where $E$ is the electric-field intensity in $\text{dB} \mu \text{V/m}$, $Bw$ is the bandwidth in hertz, $P_i$ is the spectrum analyzer reading in $\text{dBm}$, $G_{\text{sys}}$ is the total gain of the system in decibels, $L_{\text{sys}}$ is the total loss of the system in decibels, $A$ is the antenna gain factor in decibels, and 35.77 is a constant of unit conversion [10].

\[
S(\text{dBW/m}^2\text{Hz}^{-1}) = E(\text{dB} \mu \text{V/m}) - 10 \log(Bw) - 142.77 = P_i - G_{\text{sys}} + L_{\text{sys}} + A - 10 \log(Bw) - 35.77
\]

where $E$ is the electric-field intensity in $\text{dB} \mu \text{V/m}$, $Bw$ is the bandwidth in hertz, $P_i$ is the spectrum analyzer reading in $\text{dBm}$, $G_{\text{sys}}$ is the total gain of the system in decibels, $L_{\text{sys}}$ is the total loss of the system in decibels, $A$ is the antenna gain factor in decibels, and 35.77 is a constant of unit conversion [10].

All data were reduced according to the methods provided by the RFI measurement protocol for candidate SKA sites [1]. Sample observation between 230–960 MHz is shown for mode 1 in Fig. 4, the horizontal axis shows the frequency channel, and the vertical axis indicates signal magnitude in $\text{dB}(\text{W/m}^2\text{Hz}^{-1})$. Different colored curves are used to indicate the maximum (100%), 90%, 50%, 10%, and mean levels, which represent five kinds of signal level. The measurement data for both horizontal and vertical polarization modes were combined into one data set and are shown in the same diagram. The power flux density spectra in different frequency ranges have been derived by using the same reduction method. Taking the parameters of the measurement system into account, the results show an extremely good electromagnetic environment.

There are instances of RFI apparent in the data. One of the most striking, in the 240–270 MHz band in Fig. 4, is believed to be due to military satellite communications. In the L-band, there were signals detected at low levels from airplane radar during our observations. But some radio signals were self-generated: features at a frequency like 942.72 MHz were identified as radiation from the control computer. Most of the signals can be attributed to known radio services. We conclude that, due to the remoteness of the candidate region and terrain shielding, the RFI situation in Guizhou province looks very promising, with relatively little interference found between 70 MHz and 22 GHz.

C. Weather Statistics and Snapshot Observations

Guizhou Province belongs to the subtropical humid monsoonal climate region. Its climate is warm and humid, possessing the climatic characteristics of simultaneous rain and heat, clouds and little sunshine, distinctive seasons, and diverse occasional severe weather. The annual average temperature is about $14 ^\circ \text{C}$ in most areas of Guizhou. There are gales, rainstorms, thunderstorms, and snow, but no flooding or waterlog danger. Moreover, gales appear once a year, rainstorms a couple of times a year, thunderstorms on about 50 days a year, and light snow 0.4 times a year. Furthermore, the Liushui depression group which

![Sample observations for mode 1: RFI monitoring.](image-url)
Dawodang belongs may be affected by hail. A large number of observations around the Liushui area show us that the local climate is affected not only by the local elevation height but also by the local gradient, slope direction, and surface form. Therefore, the climatic spatial-temporal variations are complicated, and consequently the climatic resources are varied and abundant. As a result of fluctuating mountains and deep valleys, the spatial climatic variation (also in altitude) is quite apparent and the interregional differences are obvious in the Dawodang area.

We looked into the statistical data in Pingtang County and carried out seasonal snapshot observations at the Dawodang depression in 2005. As shown in Fig. 5, the average wind speed in Pingtang County is about 1.5 m/s, with a maximum of 12 m/s. The maximum temperature change in a day is observed to be about 7 °C in the Dawodang depression.

**IV. ACTIVE REFLECTOR PROTOTYPING**

It is known that the central part of a spherical surface deviates little from a parabolic one if a proper focal length is chosen, based on which, a novel design for a giant reflector is proposed [11]. The illuminated part of the main spherical reflector (Fig. 1) is to be continuously adjustable to fit a paraboloid of revolution in real time by actuated control, synchronous with the motion of the antenna feed while tracking an object in the sky. A standard feed system can then be employed to achieve a broad bandwidth and full polarization capabilities through the correction of spherical aberrations on the ground.

For the maximum apparent motion of celestial objects, the rate of variation is found to be lower than 5 cm/min, which enables inexpensive solutions for the mechanical control. The time designed to switch between target sources, which lie far apart, is expected to be within 10 min. To deform the reflector, it is necessary to divide the giant main spherical surface into smaller elementary units. Each element is a small part of a spherical surface, and its curvature will be optimized to get the best fit to the paraboloid.

### A. Solid Hexagonal Element Reflector

One proposed way to segment the huge reflector of FAST is to have approximately 1800 hexagons. Each element has three actuators to point its position and connect it to adjacent elements, and there should be an average of one actuator per element panel, as shown in Fig. 6.

The support with its actuator is directed towards the center of the reflector sphere. A control system based on one of the up-to-date field bus technologies was applied. If the fitting error [in root mean square (rms)] of the FAST reflector is required to be 4 mm at 5 GHz, the largest dimension of each element should not exceed 15 m. As demonstrated in Fig. 6(b), the model experiment, which had been performed by 2002 with CAS funding, approved the feasibility of the engineering concept of this FAST main reflector. From this some questions arose also. Follow-up investigations to address these questions have achieved notable progress. These include a new scheme of segmentation by triangles, kinematical study of the adaptive connector to modify its controllability, innovative tense grid design of the reflector element to lighten it and to reduce the bearing force of the actuators in the tangential direction, test on reliability and lifetime, layout of the civil engineering structure in the depression, etc. As a result, a different realization for the active main reflector of FAST was proposed [7], based on our learning and understanding of the FAST feasibility study in some key technologies.

### B. Adaptive Cable-Mesh Reflector

When a piece of massless and ideally stretched cable is slightly pulled away from the tense position at its middle, the total length varies almost imperceptibly. The increment in length of a 500-m-long cable, for example, is about 4 mm, less than $10^{-5}$ of the total when the central offset is 1 m. This suggests that an antenna surface supported by a cable net as for the Arecibo telescope could be activated to...
some extent without extra servos controlling the lengths of the supporting cables.

The focal length of FAST can be accurately determined as \( f = 0.4665R \) according to the formulas given by [4], which minimizes the peak deviation of the spherical surface from a paraboloid of revolution across \( \sim 300 \) m of illuminated aperture. The integrated length of the deformed parabola is 0.36 m shorter than the spherical curve. This small difference obtained by deformation could be achieved within the elasticity of ordinary wire cables, although the mechanical analysis is much more intricate. Instead of elastic deformation, adjusting the mesh outside the illuminated area can also compensate for this small difference in length.

Ignoring the active control, the newly proposed FAST surface adopts a similar structure to the Arecibo telescope. The cable mesh consists of two sets of cables in orthogonal directions, as shown in Fig. 7. Above the cable network aluminum plates, expanded and flattened metal mesh, or welded stainless steel mesh, is attached. The crossing nodes of the cable mesh are used as the control points. The neutral equilibrium of the reflector is taken as the optimized spherical cap. In practical implementation, one downward cable is used to realize control along the radial and tangential directions for a proper segmenting scheme, such as a Keiwiit geodesic triangle element panel shown in Fig. 7. Motors adjust these cables with feedback from the positioning system for the control points.

The feasibility of such a concept, an adaptive cable-mesh reflector for FAST, has been generally demonstrated as the main part of the FAST demonstrator at Miyun observatory. It is beneficial to future construction of the FAST telescope in the following respects: it simplifies the structure of the FAST main reflector; it eases machinery work and improves reliability; it relaxes the fabrication accuracy and leaves space for further telescope upgrading; and it reduces the civil engineering between actuators and the ground. The possible advantages listed above may be potentially beneficial to FAST in construction price, time required for the project, future operating reliability, and telescope maintenance.

V. FOCUS CABIN DRIVEN MECHANISM

FAST will be pointed by moving its focus cabin while the reflector surface is deformed. There are two groups from Xidian and Tsinghua universities working on slightly different drive mechanisms to study the feasibility of a light focus, which will be addressed in this section.

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**Fig. 6.** (a) Reflector segmentation by hexagons with actuators and (b) experimental model established around 2002 in Shanghai for testing four solid hexagonal element panels of the active spherical reflector concept.

**Fig. 7.** Cable-mesh spherical reflector: control points, cables, and motors, equipped with additional ranging system.
A. Cable Support Without Platform

A novel design for the feed-support structure of FAST, shown in Fig. 8(a), has been proposed by using six suspended cables connected to mechanical servo-control systems. The tracking will be by means of integrated mechanical, electronic, and optical technologies, i.e., mechatronics [2], [3].

The whole system will mainly consist of three parts: first, the six cables will be driven by six sets of servo-mechanisms controlled by a central computer, so that the movement of the focus cabin along its caustic trajectory can be realized. Given the difference between the apparent and required positions, where the focus cabin should point, the central computer will drive each servo-mechanism to adjust the position of the focus cabin. Secondly, a group of receivers with multibeam feeds will be mounted on a stabilizer in the focus cabin. This is to provide a second adjustment, since the focus cabin driven by cables alone may not achieve the pointing accuracy required. A laser ranging system, the third part, will be adopted to accurately measure the position of the feed in real time. The information will be fed back to the central computer for global control.

For FAST, the focus cabin can be positioned to a few centimeters’ accuracy by cable drive alone, and further to millimeter accuracy with a fine-tuning stabilizer, i.e., the hexapod. A typical hexapod consists of six variable-length actuators connecting a mobile plate to a base. As the lengths of the actuators change, the mobile platform is able to move in all six degrees of freedom with respect to the base. To demonstrate such a design, a 5-m model has been built with success to precede constructing a 50-m model at Xidian University, which has been under detailed development.

B. Cable Car Configuration

A small cable car, to house the focus cabin mounting the telescope receivers, is to be driven by two crossed pairs of parallel supporting cables, which will be suspended from two pairs of opposite towers. Additionally, a couple of downward cables could be securely fastened to corresponding anchors to be symmetrically arranged around the spherical reflector, as demonstrated in Fig. 8(b).

Positioning of the cabin would be like a trolley on the cable-way in mountains. The cabin has two rotational degrees of freedom relative to the cable car, allowing the feed to be arbitrarily pointed. Rotation of the feed can be realized by a special mounting in the car, as a way to gain a significant increase in scan range.

The pre-tension down-tie cables are introduced to adjust the stiffness of the feed support structure. The effect of the pre-tension cable for suppressing unwanted vibration can be obtained by finite-element dynamic analysis with the excitations generated according to the measured wind conditions of candidate sites. Though a precision of less than 0.1 m could be expected for reasonable tension level in the stabilizing cable, it is wise to have a secondary feed stabilizing device instead of increasing the stiffness of the whole structure to an unrealistic level. Trim masses could be used to balance the static load of the suspension cable to save energy during operation of the telescope.

The main advantages of the cable-car configuration are the following. First, the maximum length of cable extension will be relatively short, and the change may be as small as ~30 m when observing a target. Secondly, the downward cables (with a radius of ~1 cm in such a design), if applicable, could be used to adjust the stiffness and improve the dynamic characteristics of the cable support system. Thirdly, the car might be used as, to some extent, a crane during construction and maintenance of the spherical reflector, and access for maintenance can be achieved by lowering the car down to a ground platform close to the bottom of the reflector.

There were different scale models of 2, 5, 20, and 50 m dimensions established during the last decade, in a joint...
effort by Tsinghua University and the National Astronomical Observatories of China (NAOC). The final pointing accuracy of the cable car configuration achieved is 0.52 mm (≈8 arcsec) on a 50 m model, demonstrated in Fig. 9. If such a configuration is applied to the future FAST, 6 mm pointing accuracy would be expected, matching the requirement of FAST.

VI. MEASUREMENT AND CONTROL TECHNIQUES

FAST is a telescope where all parts are movable. High-accuracy measurements and control technologies are required to read the spatial coordinates precisely and quickly over long distances for both driving the focus cabin and shaping the main reflector accurately.

Measurement techniques have been tested on different scaled down models of FAST, indicating that no single technology is available on the market that could fully meet the FAST demands. GPS with a sampling rate of 10 Hz can achieve the accuracy of 1 cm only; Total Station can work over long distances but for static targets; laser trackers are of both high accuracy and high sampling rate but not over great distances; a one-dimensional charge-coupled device refreshes at 20 Hz with an accuracy of 5 mm. The inertial measurement unit owns accelerometers and gyros with high accuracy and high sampling rate but cannot work for long continuously. The feasibility studies show, however, that the requirements can be met by combining some existing techniques.

To measure the position and orientation of the focus cabin, a measuring instrument with an accuracy of 2 mm and refreshing rate of more than 10 Hz is required over a distance of about 300 m. Two laser trackers of six degrees of freedom and four total stations would be employed to observe the measuring targets mounted on the lower and upper plates of the stabilizer in the focus cabin in real time, including one redundancy each for reliability and high accuracy insurance, as shown in Fig. 10(a). The targets equipped with rotation servos communicate with the laser ranging station through an optical fiber link.

To read the profile of the main reflector, one should know the position of each node of the cable mesh. As the reflector surface will be deformed by down-linked cables, the critical displacement of a node is in the radial direction, where an accuracy of 2 mm is to be met within a sampling period of about a minute. The other components along tangents will be observed with a triangulation method by two cameras for precise control. A photographic approach would be ideal to measure the surface, as adopted by the Arecibo radio telescope in 2000. Digital scanning instruments are to be employed for measuring the positions of the control points, i.e., nodes of the cable mesh, which will be divided into nine overlapping circular sections, one at the center of the reflector, and the others distributed at moderate altitude on the spherical cap, as shown in Fig. 10(b). Each would be of 254 m in dimension and 28 m in depth with some overlaps. Each region has a cluster of three to five cameras in the center. Cameras will rotate around the axis and survey the concentric ring to make an image of the nodes in the rings. There will be 80 measuring subfields in the outer ring with a scanning period of 5 s and an accuracy of 0.5 mm. This fits well to the requirements of the measuring task for the reflector. Motors adjust these cables with feedback from the ranging system for the control points. We plan to have ~2400 targets attached to the control points on the cable-mesh reflector of FAST and to monitor positions of ~1000 targets located within and outside but close to the illuminated area when operating. The real-time position can be worked out by combining the discrete measurement and interpolation based on a kinematic and dynamical analysis.

Fig. 9. (a) Plot of rms of X, Y, Z (0.34, 0.32, and 0.21 mm, respectively) and the total errors of the car position versus observing period from the top down. (b) 50-m model demonstrating the cable car configuration reached 0.52 mm pointing accuracy.
The main reflector shape will be controlled in a semi-closed-loop system, consisting of shape sensing and adjustment. A field bus technology is applied to realize communications between the main control computer and controllers of winches, shown in Fig. 11(a). This system can also be supported by a flexible body control with additional information on the force of the cable. Primary flexible body sensors are strain gauges.

VII. RECEIVER LAYOUT

The receivers are to be mounted on a stabilized plate, connected to the main body of a hexapod in the focus cabin, shown in Fig. 11(b). The optics of FAST in Fig. 1 resembles a prime focus parabolic telescope with a maximum zenith angle of 40°, enabling the use of traditional feeds and receivers. In normal operation mode, the spill-over will come from the dish, not from the ground. Therefore, the spillover contribution of FAST to the system temperature will be less than a conventional prime focus telescope.

A bilateral collaboration on the FAST project was established between Beijing Astronomical Observatory (now National Astronomical Observatories) and the University of Manchester’s Jodrell Bank Observatory by a memorandum of understanding signed in 1999. The joint discussion on low-noise receivers is based on the use of existing, proven technology to minimize the technical risk for the project. A receiver layout was produced in 2001, followed by an update in 2006. Though traditional feeds and receivers are under current consideration, the possibility of using the not fully developed focal plane array (FPA) technology was investigated. The current FPA is not comparable with traditional horn receiver in terms of sensitivity. When it reaches its maturity, the FPA would be an ideal feed system for FAST. The current layout uses nine sets of...
receivers as given in Table 1, where the corresponding science cases are briefly listed. A trilateral collaboration with ATNF in Australia and JBCA in the United Kingdom was recently established to further optimize the receiver layout and investigate the feasibility of an ambitious 19-beam receiver at L-band with 500 MHz bandwidth. Optical fibers will be used to transfer intermediate-frequency signals to the ground-level laboratory where the signal-processing equipment will be located. Digital technology will be employed for signal processing for FAST.

VIII. MIYUN FAST DEMONSTRATOR

Preparatory studies on building huge spherical radio telescopes have been conducted for more than a decade, including theoretical analysis and experimental prototyping on key technologies of different scales as presented above. In late 2004, we started construction of a demonstrator at Miyun Astronomical Observatory, called MyFAST, aiming at assembling all key technologies to form a workable radio telescope as a scaled FAST.

The layout design of this demonstrator is presented in Fig. 12. The 252 panels and back structures are installed on a spring cable mesh structure, which is made up of 472 main cables and 145 sets of control cables, nodes, actuators, and anchors. A downward cable, which is pulled to strain the cable mesh, labeled as control cable, connects to each node. The strain force of each cable was determined by finite-element method analysis. An actuator linked each control cable to a ground anchor to shape the cable mesh.

Earth work was started first to simulate a man-made karst depression with a reservoir to catch rain water, which would be pumped away automatically. Various power lines and signal cables are attached along stairs made by concrete layers between the upper ring at ground level and the bottom of the man-made depression. Four steel towers each 12 m high were established and distributed uniformly around the man-made depression at an outer circle of 50 m diameter, following the cable-car configuration for the feed support coupled with a driven system. A cable-mesh reflector was designed by ANSYS software, deforming the

Table 1. FAST Receivers: Frequency Coverage, Number of Beams, Polarizations (RCP: Right Circular Polarization; LCP: Left Circular Polarization), Cryogenics and Science Cases Where “z” Stands for Red Shift, HI: Neutral Hydrogen, EoR: Epoch of Reionization, PSR: Pulsar, VLBI: Very Long Baseline Interferometry, Lines: Molecular Line Observations, DSN: Deep Space Network, SETI: Search for Extraterrestrial Intelligence, PTA: Pulsar Timing Array

<table>
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<tr>
<th>No.</th>
<th>Band (GHz)</th>
<th>Beams</th>
<th>Polarization</th>
<th>Cryo</th>
<th>Science cases</th>
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<td>1</td>
<td>0.07–0.14</td>
<td>1</td>
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<tr>
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<td>no</td>
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<tr>
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<td>0.56–1.02</td>
<td>1</td>
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<td>yes</td>
<td>High-z HI(EoR), PSR, VLBI, Lines, Exotic planet</td>
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<tr>
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<td>9</td>
<td>2.00–3.00</td>
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<td>yes</td>
<td>PTA, DSN, VLBI, SETI</td>
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Fig. 12. Layout design of MyFAST: a cable-mesh dish made by suspension cables and aluminum panels of 30 m aperture, focus ratio of 0.47, sphere radius of 18 m, and steel girder ring diameter of 30 m.
Fig. 13. **Cable mesh reflector of the MyFAST**: (a) deformation analysis and (b) construction.

Fig. 14. **(a) Structure of a node. (b) Design and construction of a node for MyFAST.**

Fig. 15. **(a) A handmade feed for MyFAST. (b) HI line detected by MyFAST where the line velocity is not calibrated. The peak corresponds to 70 K.**
dish surface from a sphere to a parabola, and was suspended on a girder ring of 30 m diameter, which is formed by an H-shape steel structure and supported by 16 steel pillars on the ground in Fig. 13. Reflector panels of about 1 m sized triangles are made from aluminum of 0.8 mm in thickness. Cylindrical nodes of 40 mm diameter and 156 mm height connect the main and control cables, also the reflector units by universal joints, with six ear plates on the upper and lower sides respectively, shown in Fig. 14. The actuator is composed of an ac motor, a gear reducer, a screw, limit switches, an encoder, control components, and the box. The speed of the actuator is 12 mm/s with a positioning accuracy of 0.25 mm, and the maximum stretch length is 150 mm [15]. The shape of the cable-mesh reflector has been measured by laser ranging, Leica TCRA1101 and TCRA 2003 total stations, with their supports fixed close to the ring girder. The strengths of the reflector cables have been monitored by a bow-type tensile gauge, and the difference between measured and simulated tensions is about 20% at most, which is acceptable with such simple instruments. A multilevel hierarchy structure is adopted to use for the reflector control, including a USB-CAN field bus technique employed as the middle level. A PID controller has been used in the feed driven system. The pointing of the focus cabin is measured by the laser ranger Leica TCRA1101.

Lastly, an L-band receiver for MyFAST was designed and manufactured [Fig. 15(a)] in a cheap way by NAOC. The first detection of HI in the Milky Way, shown in Fig. 15(b), demonstrated a successful construction of MyFAST as a scale model of FAST; see Fig. 16.

The full telescope FAST is under final design, with preparation for construction around July 2009. It is expected to be available for astronomical use by 2015.

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