Kilometer-square Area Radio Synthesis Telescope—KARST

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1. EXECUTIVE SUMMARY

In 1993, a large radio telescope (LT, now referred as the SKA) was proposed by astronomers from 10 countries at the 24th General Assembly of URSI. The SKA would be a telescope array with a total (effective) collecting area of about one square kilometer. There are various concepts, worldwide, for realizing the SKA project. Extensive efforts have been made, e.g., by project teams in The Netherlands (a wide-band phased array), Australia (an array of spherical Luneburg lenses), Canada (large adaptive reflector of very long focal length), China (an Arecibo-style dish), the United States (the Allen telescope array), India (an array of steerable parabolic dishes) etc., for details, see http://www.skatelescope.org. In this document we will summarize the Chinese concept for the SKA and modeling experiments for this concept.

Chinese astronomers are going to build a set of large (Arecibo-style) spherical reflectors by making use of the extensively existing karst landforms (Nan et al., 1996), which are bowlshaped limestone sinkholes named after Karst, a Yugoslavian geologist. Now we refer to such efforts for the SKA as the Kilometer-square Area Radio Synthesis Telescope project, i.e., KARST (Peng & Nan, 1997). The Chinese SKA, KARST, consists of about 30 individual elements, each roughly 200 *m* in diameter. As a forerunner for the KARST or SKA, a Five-hundred-meter Aperture Spherical Telescope (FAST) is proposed to start construction as a National Megascience Project of China, with an estimated cost of ~60 *M US$* around the year 2004. The FAST will be over twice as large as the Arecibo radio telescope coupled with much wider sky coverage (Peng, Nan & Su, 2000). Technically, the FAST is not simply a copy of the existing Arecibo telescope but has rather a number of innovations. Firstly, the proposed main spherical reflector, by conforming to a paraboloid of revolution in real time through actuated active control, enables the realization of both wide bandwidth and full polarization capability while using standard feed design. Secondly, a feed support system, which integrates optical, mechanical and electronic technologies, will effectively reduce the cost of the support structure and control system. Pre-research on the FAST has become a key project in the Chinese Academy of Sciences, and great progress has been achieved.

Some basic parameters of the FAST are demonstrated in Figure 1-1. It will have a main spherical reflector radius of R=300 *m*, a total projected diameter of up to 500 *m*, and an effective aperture of about 300 *m*. Since the focal length of FAST is to be set < R/2, a portion of the parabola (to which the spherical surface is deformed, shown by the dashed line in Fig.1-1) lies above the sphere. The geometrical configuration in Fig. 1-1 will enable the FAST to have larger sky coverage (> 40° zenith angle) than the Arecibo telescope (~ 20° zenith angle). The simplified feed system will continuously cover most of the frequency range between 300 and 2000 *MHz*, with possible capability up to 5 or even 8 *GHz* depending upon the cost.

Fig. 1-2 shows some candidate karst depressions in Pingtang county for the KARST, and the sky coverages of the FAST (with zenith angle of ~50°) and Arecibo telescopes are demonstrated in Fig. 1-3. Obviously the FAST will achieve the largest collecting area in the world. The total cost of the KARST, i.e. Chinese SKA concept, would be estimated of ~ 850 *M US$*.

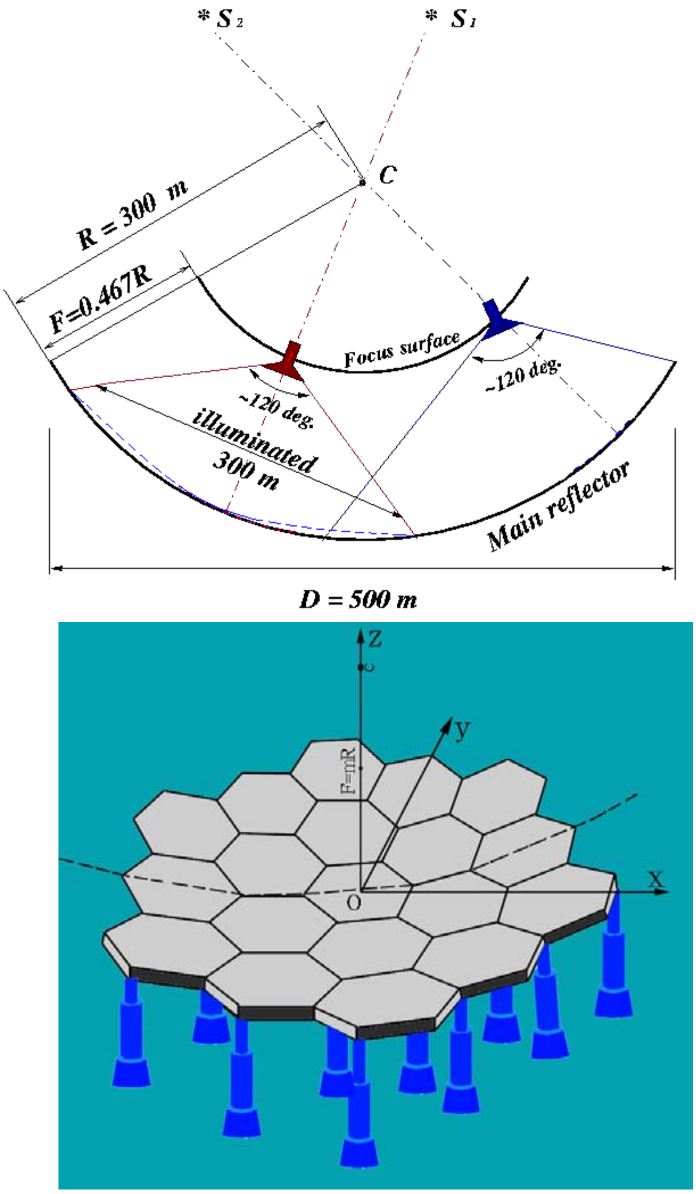


Fig.1-1 FAST concept and its geometrical configuration

2. OVERVIEW

2.1 Guiding assumptions and overall design philosophies

The SKA (LT) project was initially proposed in 1993 with a main scientific driver of neutral hydrogen observations at high redshifts. The science case also included transient phenomena of short time scales like pulsars and variable stars. Radio astronomers expect that the new tool will expand astronomical observations from the non-thermal emissions to weak thermal emissions. These need improving sensitivity by constructing huge collecting area of about one square kilometer, which is a big jump with the next generation telescope. Our project team still regards the SKA as a most sensitive low frequency telescope.

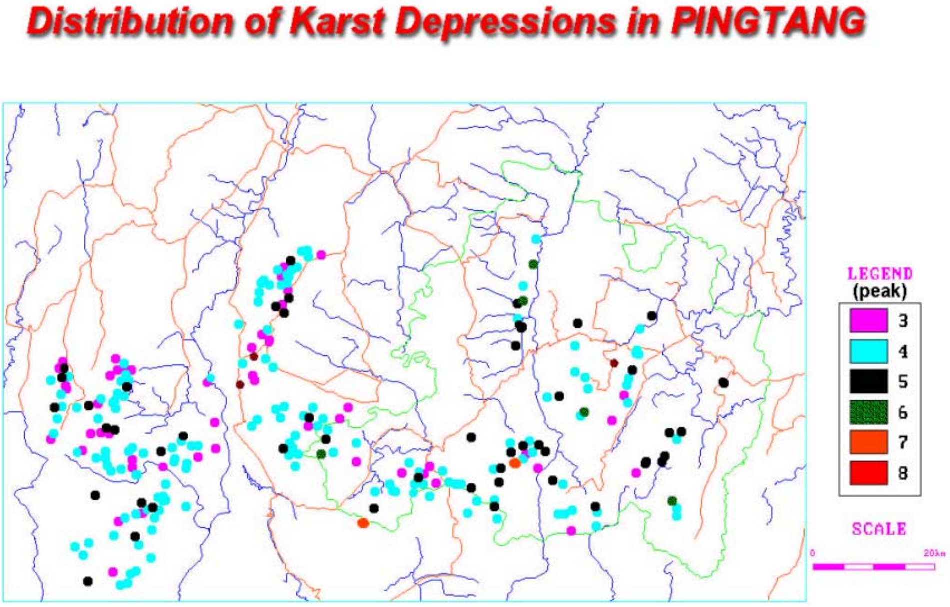


Fig. 1-2 Candidate karst depressions for the Chinese SKA, KARST

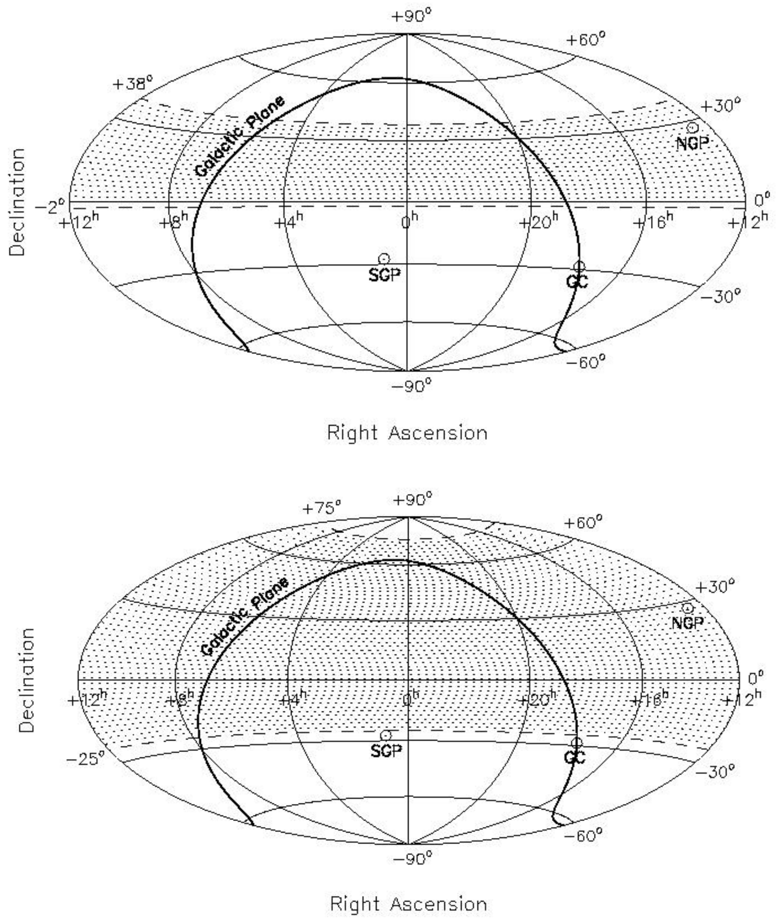


Fig. 1-3 Comparison of sky coverage between Arecibo (upper plot) and the FAST or KARST (the lower one)

The next argument is the resolution. Following the key scientific objectives of the SKA , the desired resolution would be of 1 arcsecond or sub-arcsecond. This requires an array configuration with a maximum extension of a few hundred of kilometers. Some tens of array elements will provide sufficient imaging quality and speed. High sensitivity & high resolution can be achieved by combining the SKA and the existing VLBI networks. To expand the baselines to thousands of kilometers does not benefit observations for diffused low brightness structures.

The SKA should operate at a 'limited' bandwidth, although wider frequency range covers wider scientific fields. It may be unpractical and uneconomical to combine very low and very high frequencies into one array. The ALMA and other high frequency facilities will be better options for astronomers working at short wavelengths where the objects (e.g. stellar objects) have naturally stronger emissions. Running into self-consideration, Guizhou is a very moist place, the sites do not host telescope operated up to 10 *GHz*.

2.2 Implication for cost and performance of critical design decisions

We would suggest that the SKA consists of ~ 30 unit elements with a well optimized UV-coverage. The FAST itself is a way to realize the SKA by using small number of elements. The existing large radio arrays like the VLA, MERLIN, WSRT and all VLBI networks are also configured in that way. These powerful telescopes have shown how to reconstruct complicated structures. Large number of elements may lead to signal losses in combining and transforming, design and construction complexity, possible high cost of correlation, operation and maintenance. This is also a trade off between cost and flexibility.

Single beam is necessary for VLBI observations, pulsar and SETI searches as well as monitoring telescope performance during the lifetime. We would strongly recommend multi-beam receivers at L-band (or up to C-band) and below to increase the efficiency for surveying. Ideally the FAST would be equipped with 13-beam receiver at L-band, and less number of beams at lower bands to match the sky area beamed.

3. SCIENCE DRIVERS

It is notable that almost all of the outstanding astronomical discoveries could not have been anticipated at the time that a telescope was being planed. We discuss mainly the science case of the FAST below, and in some respects, what the KARST can do.

3.1 HI in the Universe

Hydrogen is the most abundant element in the universe. Observations of hydrogen, especially the thermal radiation from cold gas rather than non-thermal emission, have close relation with some critical unanswered questions: How did the dark ages end? How and when were the first galaxies formed?

Since the collecting area of the FAST amounts to only one element of the KARST, its ability to do research on large scale structure and galaxy formation will be limited by its sensitivity and resolution. The key question will be, to what distance will we be able to detect a cool HI cloud with the FAST? A cloud of HI mass $M_{\rm HI}$ can be detected at a redshift z by a telescope of size D:

$$z = 0.033(\frac{h^2 M_{HI}}{4.7\times10^9 M_{\odot}})^{0.5}(\frac{\Delta v}{300kms^{-1}})^{-0.5}\frac{D}{100m}(\frac{T_{sys}}{20K})^{-0.5}(\frac{t}{5\min})^{0.25}$$

(Giovanelli, 1996). With Arecibo before the recent upgrade, it was possible to detect a normal S_b spiral galaxy at $z=0.04$ (for $H_o=75\ kms^{-1}Mpc^{-1}$) within an interference-free observing period of 5 minutes. With the FAST such a galaxy would be observable within 1 minute. For a simple detection (matching the spectral resolution to the galaxy's total line width) of a $M = 4.7\times10^9 M_{\odot}$ galaxy, the limiting redshift will be $z = 0.26 (f = 1130MHz)$ after 5 minutes, $z = 0.48 (f = 960MHz)$ after an hour, and $z = 0.65 (f = 860MHz)$ after 5 hours. At the indicated frequencies, the FAST will not have the resolution necessary to image such objects, but for the stronger ones it will be able to determine their velocity dispersion, in addition to redshifts. Clearly the telescope will have a role to play in HI studies at moderate cosmological distances.

The importance of observing the 21 *cm* emission line of hydrogen at high redshifts lies in its relationship to structure formation and the resulting large-scale forms. Previously, we have only been able to observe it in nearby space because the HI line is produced by thermal emission from cool or warm gas clouds (an HII region is 10 to 100 times hotter, generally producing stronger thermal radio emission), and so it is very weak and difficult to observe at large distances. The main purpose of the KARST project is to study the end of the dark ages, detecting neutral hydrogen from the precursors of galaxies using the 21 cm line emission at redshifts of 2 - 4 or even larger.

3.2 FAST as a VLBI station

VLBI has proven to be a powerful tool for investigating a wide range of compact radio sources, from masers in the Galaxy (and megamasers in distant galaxies) to AGNs at cosmological distances. In no other branch of astronomy, from infrared and optical, to X- and γ-rays, can such tiny angular scales be investigated. VLBI at radio wavelengths is absolutely unique in its capability to look into the very core of a galaxy nucleus, or at features on the photosphere of a nearby star.

When the FAST (and KARST) joins a VLBI network, the sensitivity and UV coverage of the observations will be greatly increased. The potential partners includes Shanghai, Urumqi, GMRT, VSOP, and the Pacific network of telescopes. An interesting possibility would be to create a regional network using FAST in combination with the three 64 *m* DSN-type dishes, in Ussuriysk, Usuda and Parkes. They would form a highly sensitive array with baselines to 7,000 *km*, coverage in the declination range, $20^o \le \delta \le 40^o$, and 6 hours of common observing time. Other telescopes, such as the Hawaii element of the VLBA, as well as global arrays, could also be added.

A 300 *m* effective aperture telescope in combination with a 25 *m* one has the same response as two dishes of 87 *m.* The FAST as a VLBI station will be the hub of the most highly sensitive network.

3.3 Pulsar

Pulsars are rapidly spinning and highly magnetized neutron stars. Most pulsars have been discovered in large-scale surveys using single dish telescopes like the Jodrell Bank (76 *m*), Parkes (64 *m*), and Arecibo (200 *m* effective aperture). Because of its great sensitivity, the Arecibo has found most of the faint pulsars, but its limited sky coverage has also limited the number of pulsars it discovered. In fact, the Arecibo cannot observe within 30^o of the Galactic center ($l > 30^o$), so it misses the entire pulsar population in the central region of the Milky Way. The FAST is designed to provide better sky coverage, including the entire Milky Way in the northern hemisphere, and twice the collecting area, providing greater sensitivity for searches and follow-up studies.

- Deep searches in the Galaxy.
  Let us assume that the FAST will have the same 13 beam capacity as the new Parkes 21 *cm* system. A survey of the northern Galaxy for $|b| < 5^o$ extending from $l=10^o$ to 120^o would detect some 7,000 pulsars in less than a year of observing time.
- Detect brightest pulsars in the *M31*, *M33* and other nearby galaxies.
  It has been estimated that the FAST would be able to detect some tens of pulsars in *M31* with about 10 hours of observing time. Other galaxies in the local group, like *M33*, might also turn up positive detections.
- Find tight binaries, ms pulsars, general relativity test candidates, exotics (pulsar — black hole), timing studies.
- Individual pulse studies, microstructure and polarization.
- Interstellar scintillation and refraction studies.

The FAST would provide the first opportunity to investigate in some details the pulsar population in another galaxy. It will be especially effective in deep surveys for sources such as rare types of pulsars and neutral hydrogen clouds at moderately high redshifts. Details in the structure of individual pulses, or in their polarization, might be vital. Such measurements rely on raw sensitivity: a single pulse can only be observed once. The FAST will give us the best information on the greatest number of pulsars. By observing with the KARST, some 70000 pulsars can be detected in our Galaxy and more than 1000 pulsars in our local group of galaxies.

3.4 "Normal" radio stars

Most normal stars have thermal spectra, becoming stronger at higher frequencies, and making them quite different from the low frequency pulsars. Observations of normal stars are a compelling reason for the FAST and KARST to operate at high frequencies.

- Deep surveys, order of magnitude increase in detections
- Stellar wind studies
- Nonthermal emission (OB stars with companions)
- Flares, other forms of variability and SN detections

3.5 Molecular lines

The number of molecule transitions at frequencies below 20 *GHz* is limited, but there are a few interesting ones accessible to the FAST. In addition to OH, there are the 5 *cm* methanol line, and 6 *cm* formaldehyde. They can be used to pinpoint young stars, and to study the kinematics of their ambient environment.

Recombination lines of excited hydrogen atoms are found throughout the radio spectrum. They can be studied in HII regions, and in absorption against strong continuum sources like supernova remnants. They can be used to estimate the distance to the cloud involved (by galactic kinematics), and to determine its physical conditions. Such lines are quite weak (in HII regions, less than 1% of the strength of the continuum), so studying them can benefit greatly from the sensitivity of an instrument like the FAST and KARST.

3.6 Search for Extraterrestrial Intelligent Life (SETI)

Modern astronomy concludes that planets form as a natural result of star formation, and Earth-like planets should not be uncommon. Life started on the earth and developed into an intelligent form; perhaps the same process could have happened on other planets. Biology and intelligence might be widespread in the cosmos. SETI programs are addressing humankind's greatest unanswered question: ARE WE ALONE?

Table 3-1. The number of Sun-like stars targeted by Phoenix

Transmitter Power	Parkes		Green Bank		Arecibo	
EIRP (MW)	Range (ly)	No. of Stars	Range (ly)	No. of Stars	Range (ly)	No. of Stars
1						
10			1		1.8	
100	1.4		3		5.8	1
1000	4.5	1	9	1	18	12
10000	14	5	28	45	58	390
100000	45	173	90	1430	185	12000
1000000	140	5480	280	45200	583	328000
10000000	450	173000	900	1400000	1845	13000000

Most SETI searches have been concentrated in the frequency range from 1-10 *GHz*. The Phoenix, as an example of the most comprehensive SETI program, is such a detection project. Compared to the most sensitive telescope used by the Phoenix, Arecibo, the FAST will improve the detection sensitivity by a factor of 2.5 and double the sky coverage. Therefore, the number of Sun-like stars targeted by the Phoenix within a certain range in Table 3-1 can be increased by at least 5 times. Moreover, the availability of multi-beams and large instantaneous bandwidths combine to improve the search speed as well.

3.7 Deep space network

Studies of distant planets in the solar system are essential for understanding its evolution, the origins of life, and for investigating how the deep space environment would affect human beings. In the second half of the last century, several countries, such as America and former Soviet Union, have carried out several deep space missions.

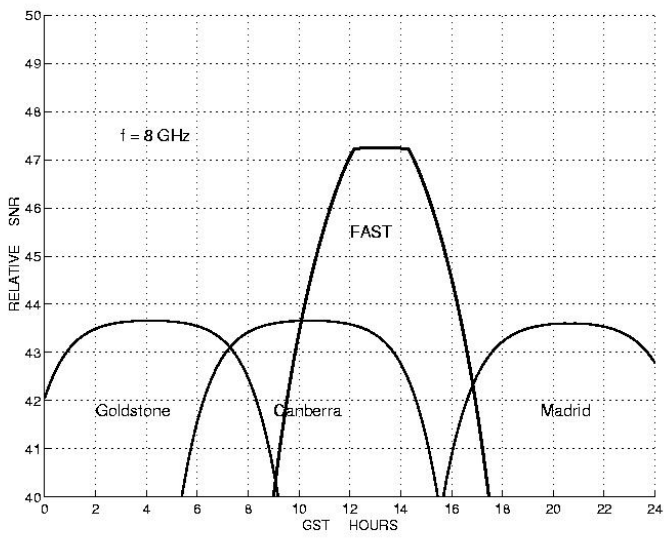


Fig. 3-1 FAST at DSN, and KARST will have about 10 times more sensitivity than FAST.

The DSN is an international antenna network that supports interplanetary space missions and radio and radar astronomy observations for exploring the solar system and the universe. At the moment, China has a control and communication network of only 36,000 *km* range using 10 *m* dishes, only sufficient to cover synchronous Earth orbit. This is a serious limitation for future work in this field, for which a large radio telescope is urgently needed. Situated in the southwest of China, the FAST will fill a gap between the sky coverage of two antennas in Canberra and Madrid in the DSN around the 17 *h* zone, as shown in Fig. 3-1, which functions better in round-of-clock monitoring without interruption.

4. PREFERRED ARRAY CONFIGURATION

In the early proposals for the SKA (Taylor & Braun, 1999) the total collecting area is divided into ~ 30 basic units (stations) clustered in a central region of 30 *km* ×50 *km*, with a few outliers at distances up to ~ 500 *km*. Subsequent proposals have more units and greater proportion at large distances from the center. Each proposal must meet the requirements of the SKA. Briefly, at 1.4 *GHz* the SKA must have the ability one degree of the sky with a resolution of 0.1 arcsec. After an 8-hr observation, the *r.m.s* noise in an image made from a single polarization channel having 640 *MHz* bandwidth should be about 0.02 μJy.

For the KARST, the Aricibo-type spherical radio telescope will be chosen as the basic unit. The advantages of a single continuous aperture telescope compared with a thinned group of concentration (Large et. al., 2001) are as the following:

- The field of view (FOV) is greater.
- There are much less energy in near sidelobes.
- Fewer receivers and phase stable link are required.
- No phasing and beam forming networks are required within the unit.
- For high dynamic range wide-field imaging, each unit of the SKA is preferably a continuous (i.e. not a thinned) collecting area.

Fig.4-1 Pingtang and Puding counties in Guizhou, China

An array that meets the sensitivity and resolution requirements consists of about 30 telescopes, each of 200-300 *m* diameter situated along a 400 *km* long east-west baseline. A 400 *km* maximum baseline produces a synthesized beam of about 0.1 arcsec while 30 dishes provide about 1 square *km* of collecting area. A 200-300 *m* dish has a primary beam with half power width of about 3-5 arcmin at 1.4 *GHz*. By means of multibeam technology, larger field of view in a sense could be achieved.

About 400 karst depressions in Guizhou Province, south of China, were selected as the candidate sites for the KARST by means of remote sensing (RS), geographic information system (GIS) and field observations. Mainly those sites are in the Pingtang (106° 4'~107° 20'E; 25° 57'~ 26° 40'N) and Puding counties (105° 40'~106° 26'E; 26° 20'~ 26° 40'N), located in the southern Guizhou, as shown in Fig.4-1.

Most of 30 units, say over 20 dishes, are located in 30-50 *km* region to configure a two dimensional random central array (Fig.4-2) and the others are located about 300 -400 *km* away from the array centre. The UV coverage of the central array, and that of the central array plus several outer dishes are shown in Fig.4-3 for observing the source 0221+276 for ~4 hr. In this case the synthesis beam profile looks better according to the analysis by Hjellming (1988).

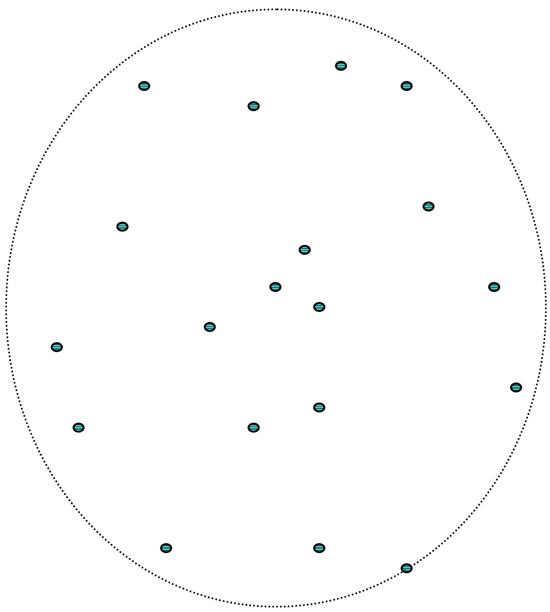


Fig.4-2 18 dishes distributed in a region of 30-50 *km* as a random array

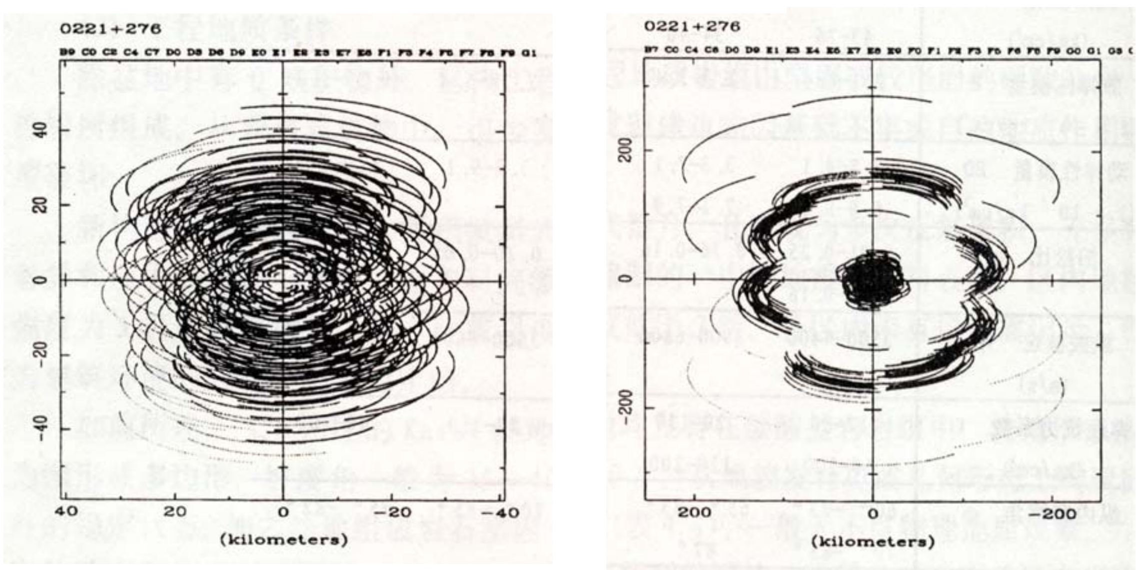


Fig.4-3 UV coverages of the central array (left) and of the central array plus some outer dishes (right).

5. ANTENNA SOLUTION

The KARST might consist of ~30 FAST-style spherical antennas distributed from dense (center) to sparse (remote) in a region of some 300 *km* × 400 *km*. Each element is sized 400-500 *m* in diameter with effective apertures of 200-300 *m*. Observing frequencies would cover from 300 *MHz* to 5 *GHz*.

5.1 Basic attributes of chosen aperture within zenith angle of 30^o are briefly tabled as follows:

Table 5-1. Expected performance of FAST and KARST

Items	Aperture 200 *m*			Aperture 300 *m*		
Bands (GHz)	0.3	1	5	0.3	1	5
Array resolution (arcsec)	0.7	0.22	0.044	0.7	0.22	0.044
FOV (arcmin)	20.6	6.2	1.24	13.75	4.125	0.825
Sidelobe level (dB)	< -17	< -14	< -10	< -17.7	< -16	~ -10
Aperture efficiency (%)	70	65	40	70	65	40
Antenna gain (dB)	54.4	68.1	74.1	54.4	68.1	74.1
Antenna noise temp. (K)			~14			~14
Effective aperture (K/Jy)				17.9	16.6	10.2

5.2 Description of Optics

Traditional feeds at the primary focus for parabola antennae could be utilized for the KARST, because the spherical reflector panels would be adjusted with actuators to simulate a parabola in real time when tracking any radio object. The optics is the same as that of primary focus optics for a parabola.

5.3 Feed options and preferred solution

Traditional feed arrangement is suggested to cover 9 individual bands. Preferred options and solution are listed as follows:

Table 5-2. Feeds and Receivers to be employed for the KARST

No.	Frequency band (GHz)	Feed type	Polariser type
1	0.30 – 0.55	Broadband folded dipole or Dikiy type	Hybrid coupler
2	0.55 – 0.64	Dikiy type or Dipole	Hybrid coupler
3	0.63 – 1.15	Broadband folded dipole or Dikiy type	Hybrid coupler
4	1.15 – 1.72	Scalar horn	1/4 λ plate + OMT
5	1.23 – 1.53	Coaxial waveguide	OMT
6	2.15 – 2.35	Coaxial waveguide	OMT+hybrid coupler
	8.00 – 8.80	Scalar horn	1/4 λ plate + OMT
7	2.00 – 3.00	Scalar horn	1/4 λ plate + OMT
8	4.50 – 5.20	Scalar horn?	Stepped septum
9	5.70 – 6.70	Scalar horn	Stepped septum

ATA-type log-periodic dipoles are not desirable for the KARST, because they may cause large gain loss, poor bandpass, undesirable illumination patterns and create more serious spillover. Besides, the focus ratio of the antenna is only 0.46 that prevents the dipoles from making use in the KARST, especially in multi-beam mode.

5.4 Sky coverage, efficiency and other performance projections

The antenna of the KARST can be pointed in any direction within zenith angle of 30^o without any extra losses of aperture as well as the antenna gain. The sky coverage could be extended up to ~ 50^o (Fig.1-1) by means of an offset illumination or dual parabola simulation (the technical details still need to be looked into more carefully) in adjustment of the panels, if some losses in aperture and antenna gain are allowed and readily corrected in observations. In the latter case, some 70% of the Galactic plane could be observed with the KARST.

5.5 Overview of any required mechanical systems

- Manufacture and calibration of panels in size of 10–15 *m*, more than 1800 actuators and a focus cabin for each antenna;
- Construction and calibration of infrastructure of reflector panels;
- Design and manufacture of feeds and cryogenic systems;
- Panels mounts on the infrastructure and backup structures and their measurements are essential mechanical items involved in the KARST.

5.6 Practical manufacturing techniques for the SKA application

Key and practical manufacturing techniques for the KARST application seem to be as below:

(1) Search and optimize distributed karst depressions for the array;
(2) Massive production and reliability trials of actuators;
(3) Massive production and measurements of panels;
(4) Manufacture and test of focus cabins;
(5) Manufacture and test of cryogenic systems;
(6) Mount, measurement and control of the reflector surface;
(7) Civil engineering between the reflector and ground.

5.7 Cost equations

If N is the number of element antenna, D is the physical diameter of the antenna in 100 meters, n the number of beams (or channels), L the average distance in 100 *km* between any station and the control center, b the number of backend equipments, then the cost (C) equations could be expressed approximately as:

$$C = N\times[D^{2.3} + 0.3\times n + 2] + (N-1)\times L + 5\times b \qquad (M\ US\$)$$

Where the cost of construction of the main surface and feed support system is taken as $D^{2.3}$, the cost of receiver of element antenna $0.3\times n$, other unexpected 2, the fiber links is $(N-1)\times L$, the backend signal processing system is $5\times b$.

5.8 Commentary on relevant previous EMT remarks

The operational frequencies of the KARST would range from 0.3 to 6.7 *GHz* instead of 0.3 to 11.2 *GHz* specified by some other groups of the ISSC. For an unprecedented sensitive radio telescope like the SKA, it is the most important to work well from about 0.3 up to 6 *GHz* to observe high-redshift hydrogen gas in the universe and the radio universe has already been well studied by using moderate instruments. It would not be necessary to cover higher spectrum that would be much better covered by some mm-wave facilities such as the ALMA.

It is difficult to realize beam forming in the KARST, because the element antenna is of very huge aperture and the corresponding primary beam of the element is already very narrow. Therefore some multi-beam systems should be installed at L and C bands to help the observations of extended sources and some kinds of survey.

6. RF SYSTEMS

One of the great advantages with the KARST is that conventional technology can be implemented. Due to the small number of receivers in the FAST, the total cost will be low. However, some new technologies such as integrated multi-beam receiver, modular MMIC, and digital beamforming techniques, are going to be applied to improve the efficiency, sensitivity and stability of the system.

The receivers are to be mounted on a stabilized station, connected to the main body of the focus cabin as a Stewart Platform. A practical collaboration on the FAST was established between Beijing Astronomical Observatory (Now National Astronomical Observatories, the NAOC) and the University of Manchester's Jodrell Bank Observatory (JBO) by a memorandum of understanding (MoU) signed in July 1999. The joint discussion of the low noise receivers for the FAST are based on the use of existing, proven technologies, to minimize the technical risk for the project. Table 6-1 summarizes the low noise amplifier (LNA) types recommended for the FAST receivers, most are either existing designs, or are currently under development at JBO. All are based on the use of High Electron Mobility Transistors (HEMTs) with the exception of the UHF receivers, and cooled by closed-cycle helium refrigerators (Baines et al. 2001).

Table 6-1 Summary of Receiver Arrangements

Rx No.	Freq. band (GHz)	Beams	Pol.	Cryo?	Compr-essors	Expected system noise temperature(K)	Uses
1	0.30 – 0.55	1	Circular	No	0	100	PSR,VLBI, HI
2	0.55 – 0.64	1	Circular	No	0	60	PSR, VLBI, HI
3	0.63 – 1.15	1	Circular	No	0	60	PSR, HI
4	1.15 – 1.72	1	Circular	Yes	1/3	25	PSR, VLBI, SETI, HI, OH
5	1.23 – 1.53	13	Linear	Yes	1	25	HI survey, PSR
6	2.15 – 2.35	1	Circular	Yes	1/2	25	VLBI
	8.00 – 8.80	1	Circular			35	
7	2.00 – 3.00	1	Circular	Yes	1/3	35	SETI, PSR
8	4.50 – 5.20	7	Circular	Yes	1	30	Survey, VLBI
9	5.70 – 6.70	1	Circular	Yes	1/3	30	Methanol

6.1 Nature of proposed solution

Receivers for the SKA will be of modular construction, using a combination of MIC and MMIC techniques. Highly integrated designs will keep the receiver sizes to a minimum, and the modular approach will allow the systems to be modified easily in future to take advantage of improvements in technology.

The low noise amplifier recommended for the FAST receivers would be operated at temperatures between 10 *K* and 20 *K*. The design of the LO/LF system is determined by the desire to deliver the entire bandwidth of each receiver to the ground equipment. A single frequency conversion has been assumed for each band, with each local oscillator fixed-tuned and phase locked to the telescope frequency standard. The common IF band has been chosen to coincide with a commercially available fiber optic transmission system.

6.2 Performance projections

The expected performance of the FAST receivers is listed in Table 6-1. The whole band is covered from 0.3 *GHz* to 6.7 *GHz*. In L-band (1.23-1.53 *GHz*) and C-band (4.5-5.0 *GHz*), we will use multi-beam receivers. These receivers are based on existing Parkes and Jodrell Bank systems, where a new design of low noise amplifier (LNA) is being developed which will be suitable for the FAST application. In other bands, single beam receivers will be used with circular polarization.

In the UHF bands (0.3-1.15 *GHz*), uncooled receivers will be implemented relatively cheap at an early stage of the project, allowing valuable radio astronomical observations to be made. In higher bands (1.15-6.7 *GHz*), cooled receivers will be implemented which allow much lower system noise temperature (25~35*K*).

6.3 Overview of associated systems

The associated systems include cryogenic cooling, vacuum system maintenance, receiver monitoring etc.

6.3.1 Cryogenics system

- **Compressors**

One possible option is the CTI 1020R with 143 *kg* weight and 635×635×813 mm^3 size, which is used by the JBO and on the VLA and VLBA. This unit has been found to be of high quality, providing reliable performance. With some precautionary weather proofing, it is also capable of outside operation, in rain and snow and to ambient temperatures below freezing. The compressors are to be mounted on the non-stabilised platform. The consideration is underway to modify the compressors (e.g. baffles in the sump) to keep them horizontal when the platform tips up.

- **Helium supply systems**

To maintain correct operating pressure for each receiver system, a helium bottle and regulator are required for each compressor, allowing individual adjustment of return gas pressure and hence optimum cooling performance.

- **Vacuum arrangements**

Two large oil-filled rotary pumps in close proximity to the receivers will be needed to evacuate the smaller dewars, but a good turbo molecular vacuum system will also be necessary for the larger dewars, including the multi-beam receivers. Being oil-filled devices, the rotary pumps must be mounted on the Stewart Platform for stabilization, which might lead to difficulties in controlling the stabilizer.

Furthermore, it is essential to monitor cryogenic temperature by Lakeshore 218 S temperature monitor, cryostat vacuum by a combined Pirami and Magnetron gauge, and helium pressure.

6.3.2 Receiver mounting arrangements

A receiver layout of the stabilized platform, lying entirely within a 4 *m* Pitch Circle Diameter (PCD), at which the actuators of the Stewart Platform, are assumed to be attached. The stabilized plate must be a relatively lightweight, yet stiff. A symmetrically formed aluminium fabrication is recommended, designed to withstand the maximum expected bending and torsion effects due to loading and environmental conditions.

The L-band multi-beam receiver, the largest one, would be located and fixed within a fabricated 'stiff' ring at the centre of the platform. The rotation of the receiver would be attained through an externally geared slew ring bearing and motor drive mechanism, its position monitored by a 16 bit encoder and its rotation boundaries checked via a series of limit switches. A similar rotation, drive and position monitoring system could be provided for the C-band multi-beam receiver, located at a set position within the receiver matrix.

All the other receivers proposed could use a single standard mechanical interface. A matrix of standard sized flanges, approximately 700 *mm* in diameter, should be designed into the stabilised platform to accommodate all of the proposed receivers in a configuration to be determined by astronomical requirements and the optimum balancing of the platform due to loading. The number of mounting points provided should exceed the current requirement, allowing for the later expansion of the receiver complement.

7. BEAMFORMING ARRANGEMENTS

The beamforming technique does not have any practical meaning for the FAST or KARST.

8. SIGNAL ENCODING/TRANSPORT

At each station, the signal will be transmitted between the focus cabin and the ground via optical fibre. The IF signal will be transported to the ground and then down-converted to baseband and digitized. The digitized baseband signal will be sent to the correlating center. The signal will be transmitted between stations via optical fibre.

9. SIGNAL PROCESSING

An extended version of current correlator technology could be adopted for the array. The baseband data could also be Fourier transformed to the frequency domain before being transmitted to the correlating center, in order to release the load on the correlator to some extent. A RFI monitoring system is required to find data segment that is affected by severe interference. The mitigation of weak interference is to be performed at the data post-processing stage.

10. DATA MANAGEMENT

The required data rate is basically determined by the observing bandwidth. A 1GBps data rate at each station would be enough for most observations. At the operating center, the data streams from all elements would have a rate of several tens of GBps altogether. These data rates are all feasible with modern data transmitting and processing techniques.

11. ARRAY CONTROL, DIAGNOSTICS AND MONITORING

Resolution requirements impose an aperture synthesis telescope configuration for the KARST, consisting of a numbers of antennae, a central correlator and an imaging process as shown in Fig. 11-1.

In the correlator, all possible combinations of the measured electric field are multiplied and averaged to result in a set of visibilities as a function of time. Once a full set of visibilities is collected, a Fourier transform produces a raw image of the radio source. The LO signals are sent to all antennae from central receiver and the IF signals back to central receiver from the output of all antennae. Therefore the bandwidth for bi-direction signal transmission would be larger than 1 *GHz*. Optical fibres could be the best way to transmit RF signal between the central receiver and antennas, with the transmission distance up to several hundred kilometers. Analogue optic fibre link systems are available commercially, covering a number of standard bands intended for use of in "antenna remoting" applications by telecommunication companies. This application has many similarities to the use of the KARST. The topological structure of such a signal transmission system will be the star type network (one point to multi-points). Optical fibre would also help the transmission of control and monitoring signals. Some spare optical channels would allow construct an Ethernet for remote control, diagnostics and monitoring of each antenna. The local control computer of each antenna is connected with central computer via Ethernet to realize remote control.

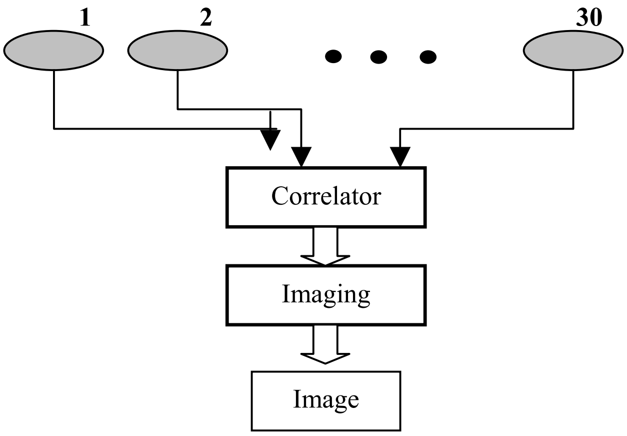


Fig. 11-1 Correlator and image of the KARST

Some principles for this control system are suggested as follows:

- High reliability, flexibility, efficiency and economics
- Modern industrial automatic technology
- A real distributed control system
- EMS compatibility
- Friendly interface

The control system based on the up-to-date field bus technology will be one of the options (Qiu & Zhu, 2001). The central computer sends all observing commands to each antenna and gets the manner information of each antenna to carry out remote control of the array in real time. The local computer will control the antenna, access the parameters of the receiver, diagnose the faults, communicate with central computer via Ethernet to remotely control the whole array. A monitoring and diagnostics system under development at Jodrell Bank could be chosen for this purpose (Baines et.al., 2001), which uses National Instrument LabView software to carry out all monitoring and diagnostics function, and can be accessed remotely. The system is designed both for regular monitoring, as part of the telescope maintenance schedule, and for diagnosis of faults. Some of the parameters that can be measured are listed below:

Monitored parameters:	Cryostat temperatures
	Cryostat vacuum readings
	Compressor pressures
	Ambient temperature
	Power supplies
Diagnostic function:	
	IF band shapes
	Spectrum of interfering signals
	Time variation of signals
	System noise temperatures (*K*)
	System sensitivities (*Jy*)
	Telescope effective area
	Receiver total power stability

12. PIVOTAL TECHNOLOGIES

12.1 Active main spherical reflector

It is well 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 giant spherical reflector is proposed (Qiu 1998). The illuminated part of the main spherical reflector (Fig.1-1) is to be continuously adjusted to fit a paraboloid of revolution in real time by actuated active control, synchronous with the motion of the feed while tracking an object. A standard feed system can then be adopted to achieve a broad bandwidth and full polarization capability through the total elimination of spherical aberrations. In the actual configuration as shown in Fig. 1-1, the center of the sphere is labeled as *C* with a rectangular coordinate system *x, y, z,* and an origin *O* at the lowest point of the sphere. The axis of *z* points to the zenith, the x-axis lies in the plane of the drawing and the *y* axis points into the paper.

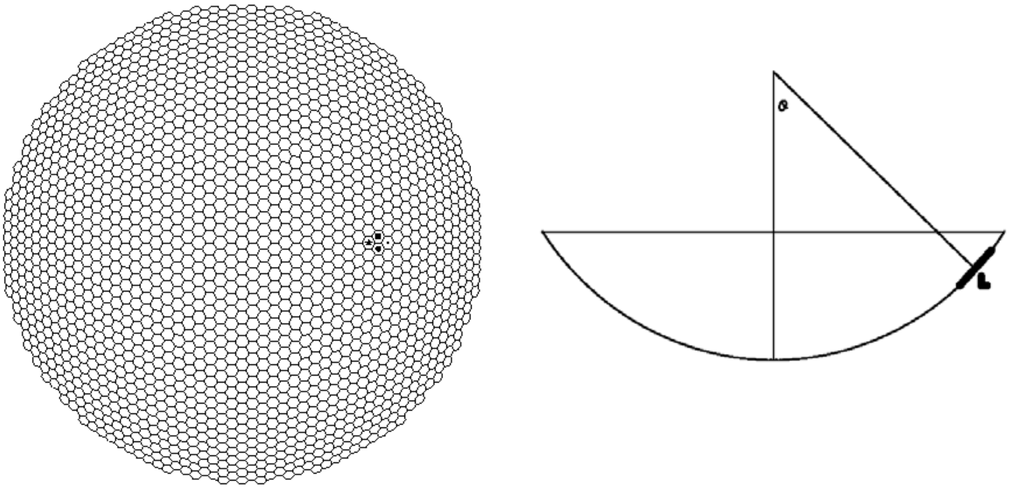


Fig. 12-1 The FAST main reflector is segmented into about 1800 hexagons.

Some basic equations of the section at $y=0$ are as follows:

Equation of sphere: $X(z) = \sqrt{2Rz - z^2}$.

Equation of parabola: $x(m,z) = \sqrt{4mRz}$ where mR is the focal length of the parabola.

Therefore the displacement between the two curves in the radial direction normal to the sphere can be given by: $\Delta r(m,\theta) = R - \sqrt{(R - z(\theta))^2 + 4mRz(\theta)}$, and

$z(\theta) = R(1 - \cos(\theta))$,

where θ is the angle as shown in Fig. 12-1.

If the focal length is set to be 0.467R (~140 *m*), the range of travel required for the actuators is under 65 *cm* across the 300 *m* illuminated aperture. The effective aperture diameter is given by

$D_{eff} = 2R \sin(\theta_o)$,

where θ_o makes the displacement between the two curves zero, i.e. $\Delta r(m, \theta_o)=0$.

For the maximum apparent motion of the celestial objects, the rate of variation is found to be very small, lower than 5 *cm/min*, which enables inexpensive solutions of the mechanical control. The time required to switch between target sources, which lie far apart, is expected within 10 minutes.

For construction, it is necessary to divide the giant main spherical surface into smaller elementary units. Each element is a small part of the spherical surface and its curvature should be optimized to get the best fit to the paraboloid. The deviation increases with the size of the unit, and with the distance from the center of the aperture. Moreover, in order to enable massive production and lower the cost of the FAST, the total number and types of the units in a good segmenting method should be as small as possible, and the units should be distributed symmetrically around the center of the reflector, which will facilitate engineering process. Fig. 12-1 shows one of the segmentation methods proposed (Su et al. 2000, Zheng 1999). Firstly, the segmentation is done in a flat plane divided into ~1800 identical hexagons with sides ~7.5 *m* long, which are computer-controlled (Fig. 1-1). Secondly, drop the plane into the spherical cap, keeping the length along the radial direction unchanged, while the dimension of the hexagon along the azimuth direction is shortened by a factor of *Sinc(θ)*.

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 shown in Fig.1-1. The support with its actuator is directed towards the center of the sphere. If the *r.m.s* of the aperture is expected to be smaller than λ/16 (~4 *mm*) at 5 *GHz,* the largest dimension of each element in Fig. 12-1 should not exceed 15 *m*. Two possible means of supporting the surface have been considered, steel cables and concrete pillars, and the final choice will depend upon the valley shape.

12.1.1 Elements of the Reflector Panel

An elementary unit is further divided into 54 plane triangles. All apexes of a triangle are on the spherical surface and the edge length of the triangle is not longer than 2.5 *m*. The reflector surface is composed of perforated aluminum panels. The thickness of the panel is ≤ 1 *mm*. Each hole in the panel is a 3 *mm* by 3 *mm* square hole or 3 *mm* diameter circular hole spaced by 6 *mm* between two adjacent centers. The net area of the panels is almost 75% of the gross area of the reflector. The surface area of an elementary unit is 146.142 m^2. The total area of the reflector surface is approximately 261300 m^2. If the thickness of the panel is 1 *mm*, the total aluminum quantity needed for the reflector panels is ~ 558 T.

12.1.2 Supporting structure of the reflector

There are two alternative structure-supporting systems. i.e., plane structures and space structures. Comparing the two systems, the space structure is better for the supporting structure of the reflector to obtain better spatial stiffness, better integrity, lighter self-weight, easier fabrication and lower construction costs. The double layer grid shell with triangular-pyramid patterns would be selected for the supporting structure of the reflector.

A Typical grid shell is shown in Figure 12-2. All left joints are on a spherical surface and all right joints are on a concentric spherical surface. The triangle grid size of the shell is not greater than 2.5 *m*. The structure height is chosen between 1.2 and 1.5 *m* to achieve a balance between stiffness requirement and construction cost. There are three supporting joints under a structural unit. They are evenly and alternatively distributed at the structure corners, shown as point markers in Figure 12-2. Each supporting joint is attached through mechanical devices to a servo control actuator that allows adjustment of the position of the corner with millimeter precision. The maximum range of height variation for any actuator is 67 *cm* and the maximum rate of variation is 4.4 *cm/min* for tracking the object.

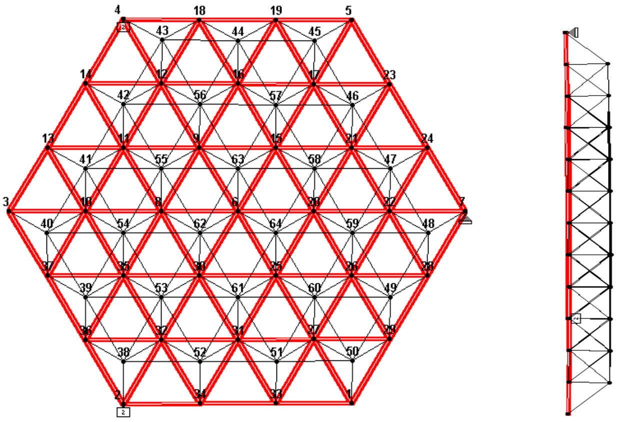


Figure 12-2: A typical grid shell as a supporting structure.

Two different structural materials – steel (Q235, Chinese standard steel that is equivalent to ISO630Fe360) and aluminum alloy (AA6061 T6) – are selected for comparison. The stainless steel as a weatherproof structural material is not discussed because of its high construction cost. Two different structural limiting states, i.e., the load-bearing capacity limit and the deformation limit, under normal working conditions, and twelve different load combinations were considered in the analysis and design of the supporting structure. Under the load-bearing capacity limit, the supporting structure is mainly subject to self-weight, ultimate wind load (base wind pressure =0.35 kN/m^2), temperature change ±30 ^{0}C) and possible snow load. Moreover, the supporting structure must ensure the geometrical accuracy of the reflector surface under normal working conditions: the structure is subject to self-weight, working limit wind load (average wind speed =4.0 *m/s*), and temperature change (±20 ^{0} C).

A steel structure generates larger tangential reactions on the mechanical devices than the aluminum alloy structure does. This will increase the cost of the mechanical devices and the servo-controller actuators. An aluminum alloy structure has many advantages that meet all the requirements of the supporting structure of the reflector. Although its cost in the construction period is higher than a steel structure, its maintenance cost in operation is much lower. In general, the total costs of these two structural systems are well matched. Therefore, an aluminum alloy structure would be the best choice.

12.1.3 Control system of the reflector

The control system based on the LonWorks technology is demonstrated in Fig. 12-3 (Qiu & Zhu 2001).

The system consists of two levels, the upper level is the master computer and the lower one consists of about 1800 intelligent nodes, connected with the master computer via a network. The master computer may consist of several Personal Computers. LonWorks control networks offer a feature called "distributed processing" whereby each device in the network can receive, transmit and process network information independently of other devices. This means that devices in a LonWorks control system can make decisions and process information without the need for a PC, programmable logic controller (PLC), or some other form of central host processor.

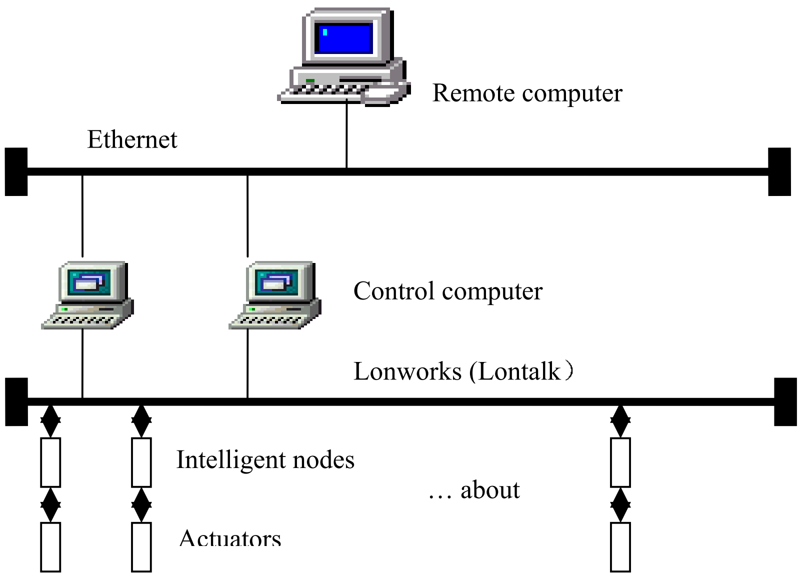


Figure 12-3: The block diagram of the control system for the active main reflector.

12.1.4 Model

In order to investigate the loading behavior of the supporting structure, the functionality and the reliability of different mechanical devices, and the environmental effect on the whole reflector, a 1:3 scale model composed of four elementary units was designed. The principle of analogy is applied in the design. Twelve load combinations are also considered. Because the original grid size is rather irregular, it is adjusted for optimal design and the convenient construction.

Figure 12-4: A 1:3 scale model of the FAST reflector.

Two different structural materials are also used in the model, i.e., three different steel grid shell structures are used in three units and an aluminum alloy grid shell structure is used in one unit. The scaled model of the FAST active reflector had been installed and tested successfully in November 2000 (Fig.12-4).

12.1.5 Overview of the reflector of other SKA projects

A number of different concepts of the SKA are being studied all over the world to realize the SKA, each has its own features and limitations. Besides the FAST, another way as a single reflector is to use a large, low profile parabolic reflector surface with large F/D ratio. The surface would be adaptively modified for steering with a receiver, pointed by a flying vehicle in the prime focus. A Canadian project team at the National Research Council is pursuing this approach.

The option to form a station with a large number of small to medium-sized steerable parabolic dishes is being studied both by the SETI institute in the US and the NCRA in India. A possible SKA concept of small Luneburg lenses has been proposed by Australian astronomers. At the other extreme of the conceptual spectrum, to allow independent multi-beaming and offer an exceptional flexibility for the application of RFI suppression techniques, both ASTRON and ATNF project teams are working at the phased array approach.

12.2 Feed support

The FAST is "pointed" by moving the feed cabin, while the reflector surface is deformed in synchronism with the feed pointing motion. One of the pivotal technology of the Chinese SKA concept is the platformless feed support system, which has the potential to reduce construction expenditure, provided the vibration level of the feed can be controlled to what required.

12.2.1 Cable support system

A new design for the feed-support structure (Fig. 12-5) for the FAST/KARST has been proposed by using six suspended cables connected to mechanical servo-control systems (Duan et al. 1996). The main idea is to move the feed along the focal locus dynamically by adjusting lengths of the suspension cables according to the position of feeds. However, the wind-excited vibrations of feed are estimated to be around 0.5 *m* in *r.m.s*, so a secondary feed-stabilizer has to be employed. At present, the Stewart parallel mechanism is chosen as the stabilizer and under development.

Compared with the Arecibo 305 *m* radio telescope, the total weight of the feed support system could be evidently reduced by two orders or more in such a design, probably from nearly 10,000 (if Arecibo-like support taken) to a few tens of tons. The tracking will be by means of integrated mechanical, electronic and optical technologies, i.e., optomechatronics.

The whole system will mainly consist of three parts: firstly, 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 feed (cabin) should point, the central computer will drive each servo-mechanism to adjust the position of the feed. Secondly, a group of receivers with multi-beam feeds will be mounted on a stabilizer in the focus cabin. This is to provide a second adjustment, since the cabin driven by cables alone may not achieve the pointing accuracy required. A laser ranging system (in our case three Total Stations of TCRA 1101 plus), being 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 loop control.

Numerical simulations have been carried out for such a design by both nonlinear response analysis of the cabin-cable system with respect to random wind (Su & Duan 2000a), and precision study of the fine-tuning stabilizer using inverse positional computation, kinematics and singularity analysis (Su & Duan 2000b, Su et al. 2001). Detailed deductions (Duan 1999, Su & Duan 2000a, Su & Duan 2000b, Su et al. 2001) have shown that the optomechatronics design is capable of satisfying the pointing accuracy required.

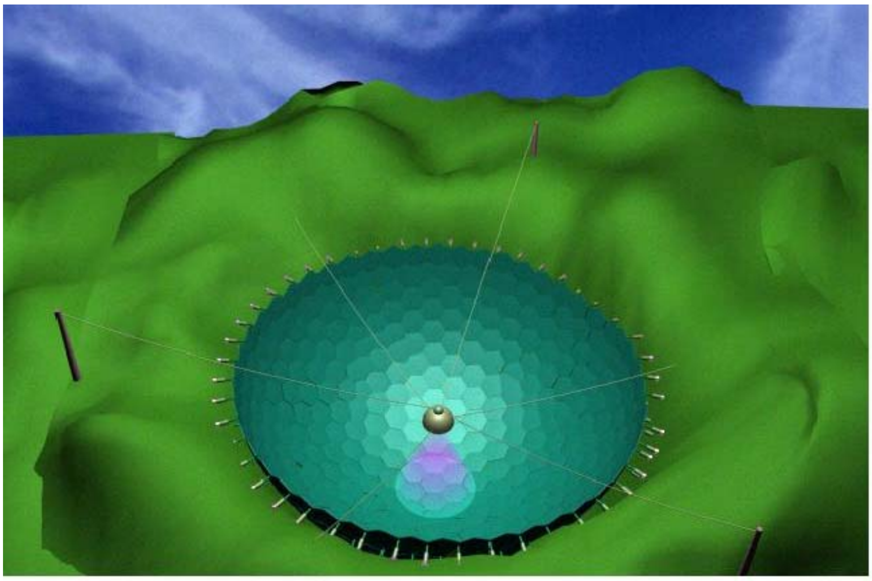


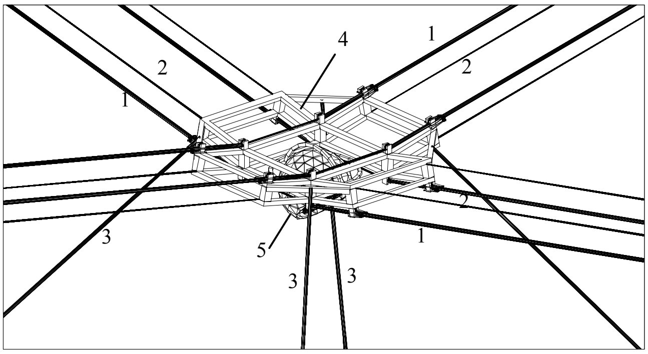
Fig.12-5 Cable support system without a platform

Fig.12-6 A 50 *m* × 50 *m* × 15 *m* model of the cable-support structure developed

To demonstrate the design, a 5 *m* model has been built with success to precede constructing a 50 *m* model, which is constructed as shown in Fig. 12-6. For the FAST the focus cabin can be positioned to some tens of centimeters accuracy by cable-driven only, and then further to millimeter accuracy with a fine-tuning stabilizer, i.e., the Stewart platform. A typical Stewart platform 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.

12.2.2 Cable car configuration

In line with the platformless conception, researchers in Tsinghua University proposed a cable-car feed support system in 1998. A small cable car, to serve as the focus cabin housing the feed and receivers, is to be driven by eight cables (Fig. 12-7). Two pairs of parallel supporting cables will be suspended from two pairs of opposite towers (instead of the three in the concept discussed above), while another four downward cables are securely fastened to four anchors which are symmetrically arranged about the main spherical reflector (Ren et al. 2001), to increase the stiffness of the system. The lengths of the connecting cables would be adjusted appropriately as the cabin location changes. Such a design aims to increase the stiffness of the platformless cable support structure discussed above.



1: suspension cable; 2: driving cable;
3: pre-tension cable; 4: cable car; 5. feed cabin

Fig.12-7 Cabin car driven by 2 pairs of parallel supporting and 4 downward cables

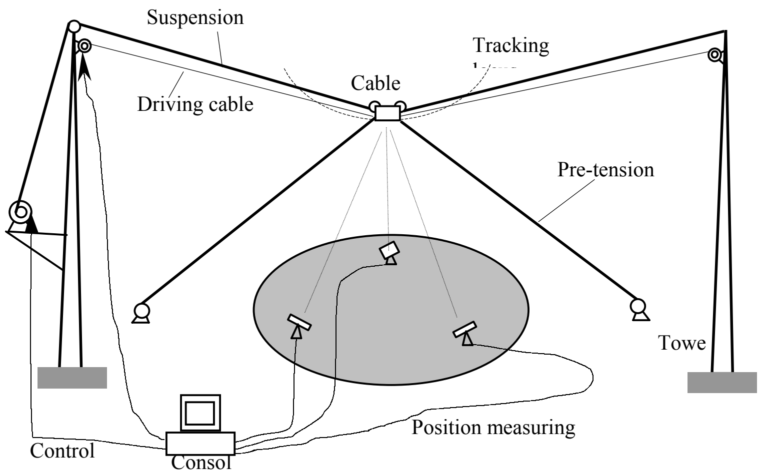


Fig. 12-8 The general assembly of the cable car feed support configuration

Positioning of the cabin would be achieved by driving the car on two crossed sets of supporting cables, which is like a trolley on the cable-way in mountains. The car can move in two directions with the two sets of suspension cables as tracks. And the cabin has two rotational degrees of freedom relative to the cable car, which allows the feed to be arbitrarily pointed, irrespective of what the orientation of the cable car is. Rotation of the feed can be realized by a special mounting in the car, the axis of which should intersect the center of gravity of the cabin. Rotating the feed about its phase center is a way to gain a significant increase in scan range. Beam pointing is unaffected and the net result is that the aperture is fed in an offset manner. The only penalty incurred is the appearance of cross-polarized lobes in the plane orthogonal to the plane of scan. For circular polarization this becomes a small beam squint in that plane. Actuators are to be employed for actively controlling any oscillations of the cabin induced by the motion.

The cable-car configuration is demonstrated in Fig. 12-8. The pre-tension 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 about 0.5 *m* can 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 can be used to balance the static load of the suspension cable for energy efficiency during operation of the telescope.

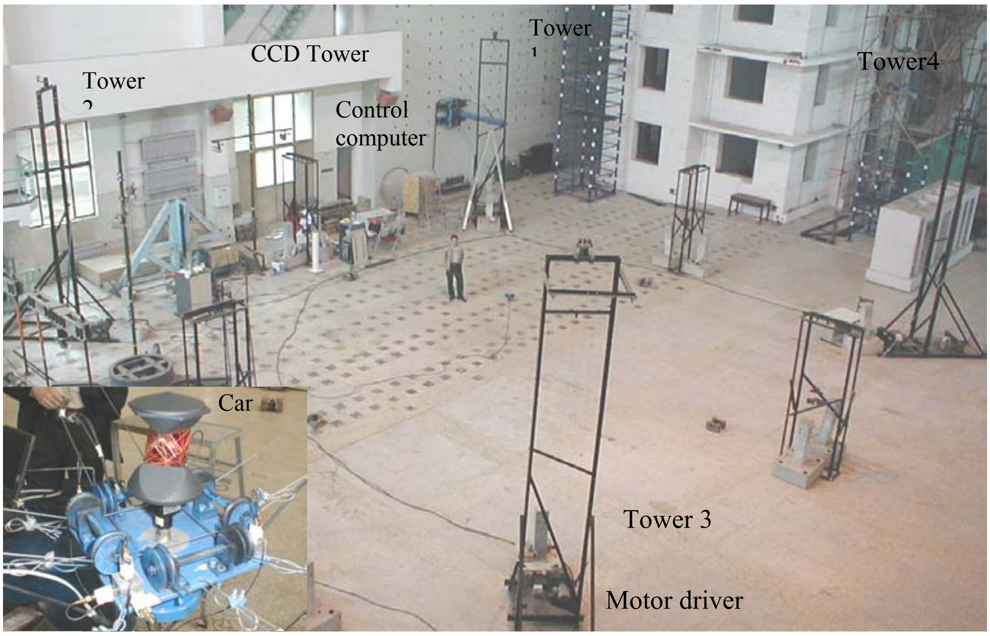


Fig. 12-9 Scaled model of 1:30, 20 *m* × 20 *m* × 6 *m* cable-car configuration

The cable-car configuration separates the positioning and pointing of the feed, but uses 7 degrees of freedom to control 6 degrees of freedom of the feed. Characteristics and vibration reduction effects of the pre-tension cables have been discussed in the cable-car configuration by Ren et al. (2001). A 1:30 scale physical model for the cable-car system has been constructed (Fig.12-9), in terms of the model similarities, the performance of the prototype can be predicted. The predicted position precesions for the first support system is below 0.5 *m* in *r.m.s* under wind conditions of 8.2 *m/s* at the candidate sites. A 1:5 scaled model for the Stewart stabilizer (to stabilize its lower platform by compensating any vibration of its upper one with variable-length actuators) are constructed, as shown in Fig. 12-10, for feasibility study with the available and proposed technologies. The control effects are also encouraging but still below the specification.

The positioning accuracy of less than 2 *cm* is reached by support of the cable-car for the present model, and of about 36 *cm* could be predicted by similarity law for the FAST at the wind speed of ~ 8 *m/s*. The main advantages of this cable-car configuration are the following: firstly, 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), can be used to adjust the stiffness and improve the dynamic characteristics of the system. Thirdly, the car could be used as a crane during construction and maintenance of the main spherical reflector, and access for maintenance can be achieved by lowing the car down to a ground platform close to the tower foot.

Fig. 12-10 Stewart platform: scaled model of 1:5 for FAST

13. PROPOSED SKA LOCATION

A large number of karst depressions in Guizhou province, at least 400 depressions at Pingtang and Puding counties, were investigated with Remote Sensing (RS), the Geographical Information System (GIS) and on-the-spot observations, and selected as candidate site locations (Nan et al. 1996) for the SKA. As an example, Fig.13-1 shows statistical results for Pingtang county. More than 10 depressions were imaged at the high resolution of 5 *m/pixel*, showing suitable profiles for a large spherical reflector (Peng et al. 1997).

In the selected sites, carbonate rock is the main hydrous layer. Wind speed measurements made near the ground at various heights above depressions were started in January 1999. The speed grows from ~1 *m/s* in the bottom of the depressions to maximum ~7 *m/s* at the top. There are less than 5 days of snowfall per year, and no ice build-up at the sites (Nan et al. 2000). A series of measurements at various sites has been carried out to check on their suitability, from the point of view of radio interference, for realizing the FAST/SKA. The first measurements were made at 8 karst depression sites in Nov. 1994 in both Pingtang and Puding counties. Further measurements were made in March 1995 for a period of one month in an attempt to understand distance effects. In June 2000, we re-monitored half of the above sites to see the change of interference with time. The results of these measurements provide information about the frequency, strength and characteristics of the interfering signals. Most of the interfering signals found appear to be narrow-band (< 10 *kHz*) beacon signals of unknown origin.

Due to the remotness of this region and local terrain shielding of karst hills, preliminary results of radio interference monitoring are quite promising (Peng et al. 1996, Nan et al. 2000). Furthermore, the major electric network (from West to East) in China is passing through some counties (including Pingtang and Puding) of the province, without any problem to supply (total power over 500 *kV*) for the potential use of the FAST/KARST. In addition, optic fibre access for communications is available to every towns and villages of the province, providing ability of data transmission of the FAST/KARST. The annual average temperature is about 16º C with few days of frost and snow.

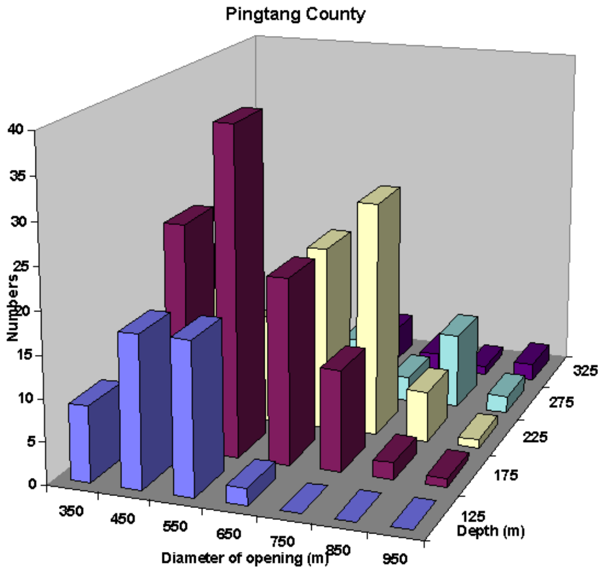


Fig. 13-1 Statistics of Pingtang county depression geometry

14. REPRESENTATIVE SYSTEM PERFORMANCE AND COST ESTIMATES

Table 14-1 Expected performance of KARST

Items	Aperture 300 *m*		
Bands (GHz)	0.3	1	5
FOV (arcmin)	13.75	4.125	0.825
Total sky coverage	68%	68%	68%
Array resolution (arcsec)	0.7	0.22	0.044
Antenna noise temp. (K)			~14
Effective aperture (K/Jy)	17.9	16.6	10.2

The cost (C) equations could be expressed approximately as (see Sect.5.7):

$$C = N\times[D^{2.3} + 0.3\times n + 2] + (N-1)\times L + 5\times b \qquad (M\ US\$)$$

For example, the cost of the FAST, the pilot element of the KARST, could be estimated as:

$$C = 5^{2.3} + 0.3\times 30 + 2 + 5\times 2 = 61.5 \qquad (M\ US\$)$$

The major cost would be spent on construction of mechanism, and the electronic system would be a special use for radio astronomy, so the whole cost will be maintained approximately constant in the nearly 10 years. The cost of the KARST would be estimated of about 850 *M US$*, and the operation cost per year is about 5 percent of the construction cost plus the usual upgrading funds available for any major facility run in China.

15. CONCEPT DEMONSTRATORS

The two key technical issues, i.e., active main reflector and cable supporting structure for the focus cabin, have been intensively investigated and tested in the past years, as demonstrated mainly in Sect.12. The feasibility study of the KARST concept is nearly completed by March 2002. During testing all kinds of scaled models, some problems were emerged and to be improved in order to reach a practical design of the FAST/KARST, such as the pre-tension support for the active main reflector, dynamical coupling of the cable driven structure of the feeding system (between the cable support system and Stewart stabilizer). We are now at the position to modify the scaled models, a 50 m new scaled model, which includes the cable-car supporting structure and the active main reflector, would be constructed as the KARST concept demonstrator around late in 2003. The key technologies for the platformless feed system could be tested. It can also be used as a real telescope to observe some radio sources or satellites.

The key technologies involved in the platformless feed support system are:

- Position control of the feed with a number of frequency-variable motors to adjust lengths of suspension cables without delay and without inducing vibrations of the feed.
- The manufacture and control of a Stewart parallel platform: a size of 10 *m* × 10 *m* × 6 *m* and payload 5000 *kg*, static position precision of less than 1 *mm*, and dynamic position precision less than 4 *mm* at site wind.
- 3-D position measurement system (e.g., Automatic total station, a laser ranging system) of dynamic precision less than 1 *mm*, updating rate larger than 10 *Hz* (present available 5 *Hz*).
- Vibration suppressing technology for cable structures under various windloads.

16. SYNERGIES WITH OTHER SKA CONCEPTS

The FAST team started long-term and close cooperation with the Arecibo Observatory since the concept was initially proposed in 1994, learning the technical and scientific developments at the observatory. This link is of critical importance for the FAST design and construction, although the Arecibo Observatory is not formally involved in the SKA project.

A collaboration on the FAST was established between the BAO and JBO by a MoU signed in July 1999 after productive exchanges and contacts of years. As a part of the collaboration, JBO engineering group visited the NAOC and took part in discussions of the focus package for the FAST. A complete technical report on the layout of the arrangements in the focus cabin and related issues has been prepared by the JBO. This successful link between the NAOC and JBO will continue due to the survival time of the FAST project. The FAST cooperates with the SKAI team in developing the science case for the SKA and FAST itself, discussing the system design, material technology, interference rejection and etc.

The LAR, the approach being pursued by the Canadian team is another way to realize a single reflector station by using a large, low profile parabolic reflector surface with large F/D ratio. The surface would be adaptively modified for steering with a receiver realized by a flying vehicle in the prime focus. There certainly are many similarities between the LAR and FAST in number of engineering aspects – reflector adjusted by large amount of computer controlled actuators, long cables applied to the focus support, accurate positional measurements for those dynamical structures with high sampling rates, theoretical study, dynamics analysis, and computer simulating on the soft structures of large scales. Some exchanges occurred previously, more collaboration would be bi-directionally beneficial.

17. APPENDICES

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