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Two New 30-meter Telescopes for Observing Interplanetary Scintillation

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Abstract

The solar wind is a high-speed stream of charged particles originating from the solar corona and continuously radiating outward. Investigating the formation mechanisms of the solar wind and its propagation and impact in interplanetary space provides crucial support for both space science research and space engineering. The newly constructed Interplanetary Scintillation Telescope under the Meridian Project II aims to monitor the propagation of background solar wind and solar storm disturbances in interplanetary space. This telescope system adopts an observation mode of one main station and two sub stations, with the sub stations equipped with two 30-meter parabolic telescopes. This paper primarily focuses on the development and performance of the 30-meter telescope.

1. Introduction

Solar wind is a stream of charged particles emitted by the Sun, primarily composed of electrons, protons, and a small number of heavy ions. These charged particles are ejected from the solar corona into interplanetary space at ultra-high velocities (hundreds kilometers per second), forming a continuous plasma flow. The solar wind exerts significant influence on the magnetospheres of Earth and other planets, triggering auroras, disrupting radio communications, and affecting the normal operations of satellites and spacecraft. Interplanetary scintillation refers to the phenomenon when the radiation from a distant compact radio source propagates in the interplanetary space, it is scattered by the turbulent irregular structures of the solar wind, resulting in random fluctuations in the observed radio flux. Ground-based interplanetary scintillation observations can not only measure the solar wind speed at a wide range of heliocentric distances and high heliographic latitudes, but also provide long-term monitoring of interplanetary space and track the propagation of interplanetary shock waves[1].

The Meridian Project is a comprehensive ground-based space environment monitoring system. Building upon Phase I of the Meridian Project, Phase II has added a series of advanced solar-interplanetary monitoring equipment, forming a full-chain monitoring capability for the Sun-Earth space environment. The interplanetary space is a key transmission channel that links the solar atmosphere and the Earth's space[2]. Therefore, the Meridian Project II has constructed an interplanetary scintillation (IPS) telescope for monitoring the background interplanetary solar wind and the propagation of solar storm disturbances. The interplanetary scintillation monitoring telescope adopts a cooperative observation mode with one main station and two sub-stations. The main station is equipped with parabolic cylindrical antennas (at 327 MHz and 654 MHz), located in Mingantu, Inner Mongolia. Two 30 meter parabolic telescopes (at 327 MHz, 654 MHz, and 1400 MHz) are built at the two sub-stations, which are located in Yihe Gaole, Inner Mongolia and Wurigen Tala, Inner Mongolia respectively showed as Figure 1. The distance between the three stations is approximately 200 kilometers, forming a network layout similar to an “equilateral triangle”. They collaboratively observe and record the spatio-temporal variation characteristics of interplanetary scintillation transient signals. Through cross-correlation analysis of multi-temporal scintillation data, the system measures the velocity of interplanetary solar wind[3].

Figure 1. Left: The telescope located in Wurigen Tala. Right: The telescope located in Yihe Gaole.

This paper focuses on the two 30-meter IPS telescopes at the sub-stations, with their main performance parameters listed in Table 1. The IPS telescope at the sub-stations consists of a 30 - meter antenna system, an analog signal receiving system, and a digital signal processing system. The IPS radio signals are received by the antenna, then sequentially amplified, filtered, and sampled by an AD converter. Based on the radio observation time-series data, power spectrum transformation is performed, and the raw power spectrum data is stored. Subsequent power spectrum fitting analysis yields solar wind parameters.

Table 1. Main Specification

Antenna	30m
Frequency	327 MHz, 654 MHz, 1400 MHz
Frequency Bandwidth	40 MHz
Frequency Resolution	1 MHz
Polarization	Dual-linearly-polarized
Dynamic Range	65dB
Sensibility(Yihe)	0.108Jy @327MHz/1s 0.085Jy @654MHz/1s 0.038Jy @1400MHz/1s
Time Resolution	1 ms

2. Antenna System

To meet the requirements for high-precision measurement of weak Interplanetary Scintillation (IPS) signals, two fully steerable 30-meter aperture radio telescope antenna systems were designed and constructed. The antenna system primarily consists of core components such as the antenna reflector, feed system, azimuth-elevation drive mechanism, and servo control system. Specifically, the high-performance mesh reflector is used for the reflection and focusing of electromagnetic waves; the dual feeds system with a stable phase center enables efficient reception and high-sensitivity detection of electromagnetic waves; the azimuth-elevation drive mechanism, serving as the mechanical actuator of the antenna, works in conjunction with the servo control computer to achieve precise pointing control of the antenna.
This system mainly realizes the function of receiving radio signals in the frequency bands of 327MHz±20MHz, 654MHz±20MHz, and 1400MHz±200MHz with vertical polarization and horizontal polarization. To ensure reception efficiency across these frequency bands, the feed system adopts a segmented design for low and high frequency bands: the 327MHz and 654MHz bands utilize a cavity dipole feed structure, while the 1400MHz band employs a longitudinal slot horn feed structure, shown as Figure 2. The two feed assemblies are mounted on a rail system, enabling rapid switching between different frequency band feeds through precise sliding on the rails. This design not only ensures the operational efficiency of the system but also achieves flexibility and reliability in multi-band reception.

3. Analog System

For the dual-feed antenna system, the analog receiver system adopts a dual-channel design, covering the three frequency bands of 327 MHz, 654 MHz, and 1400 MHz respectively. The 327 MHz and 654 MHz bands utilize room-temperature receivers, while the 1400 MHz band employs a cryogenically cooled receiver to enhance sensitivity.

Figure 2. Left: The cavity dipole feed for 327MHz and 654MHz. Right: The longitudinal slot horn feed for 1400MHz.

The room-temperature receiver consists of low-noise amplifier, frequency divider amplifier, noise source unit, and intelligent power supply and monitoring unit. The low - noise amplifier is directly mounted at the antenna output port, and its output signals (327 MHz ± 20 MHz and 654 MHz ± 20 MHz) are fed into the frequency - dividing unit through a transmission cable. The frequency division unit also provides power to the low-noise amplifier. The integrated power division and filtering circuit within this unit splits the input signal into two segments, each with a bandwidth of 40 MHz. After subsequent amplification and equalization processing, the unit outputs one vertical polarization and one horizontal polarization analog signal for both the 327 MHz ± 20 MHz and 654 MHz ± 20 MHz frequency bands.

The cryogenically cooled receiver consists of six functional modules: the cryogenic microwave unit, the room-temperature microwave unit, the noise calibration unit, the intelligent power supply and monitoring unit, and the refrigeration system. The cryogenic microwave unit, serving as the core component of the receiver, includes devices such as the microwave vacuum window, thermal insulation components, cryogenic low-noise amplifiers, and cryogenic RF cables. These components are encapsulated within a vacuum Dewar maintained at an ultra-low temperature by the refrigeration system. The polarizer and low-temperature low-noise amplifier work at a 20 K platform, receiving 1.4 GHz ± 20 MHz radio signals, decomposing them into vertical and horizontal polarization signals, and then amplifying with extremely low noise. The room-temperature microwave unit in the indoor section contains post-amplifiers, filters, and digitally controlled attenuators. It performs secondary amplification, filtering, and attenuation control on signals from the cryogenic unit, ultimately transmitting the processed signals to the digital processing system.

4. Digital System

The digital signal processing system is primarily responsible for raw data acquisition, autocorrelation power calculation, and integration over a 1 ms time window for dual-polarized signals within the frequency range of 327 MHz, 654 MHz, and 1400 MHz. The system consists of four core functional modules: the data acquisition and signal processing unit, the clock synchronization unit, the data storage unit, and the display control unit. As the core processing module of the system, the data acquisition and signal processing unit adopts the high - performance analog - to - digital converter AD9694BCPZ - 500 from ADI Company. This chip features a 14 - bit quantization accuracy, a maximum sampling rate of 500 MSPS, and a 4 - channel parallel processing capability. Its full - power analog input bandwidth can reach 1.4 GHz, fully meeting the system's technical requirements for an analog input bandwidth of 1.4 GHz ± 20 MHz and the ADC sampling quantization bit - width. By configuring two ADC chips, the system can achieve synchronous acquisition of 6 - channel analog signals, with the sampling clock frequency set at 200 MHz. The clock synchronization unit is responsible for generating the 10 MHz/100 MHz synchronous clock signals required by the system, providing an accurate timing reference for the data acquisition and signal processing unit. The data storage unit is tasked with storing the collected and processed data into the designated storage medium, providing a reliable data source for subsequent data processing and archiving. The display control unit undertakes core control functions such as system program loading, parameter configuration, and operation status monitoring, ensuring the stability and reliability of the system operation.

5. Conclusions

This paper provides a detailed account of the construction of two newly added 30-meter radio telescopes dedicated to Interplanetary Scintillation (IPS) observations within the framework of the Meridian Project Phase II. The overall architecture of the observational system is outlined, and the key hardware components of each subsystem are described. Currently, the construction of the parabolic cylinder antenna at the main station and the parabolic antenna at the sub-station has been completed. The research team is actively working on optimizing the data calibration pipeline, and preliminary observational data have been acquired, laying the foundation for subsequent scientific investigations.

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