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A Brief Introduction of Antenna Arraying for China's Tianwen-1 Mars Exploration Mission

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Abstract

This paper provides a brief introduction to the development and use of antenna arraying in China's Tianwen-1 Mars Exploration Mission. Major elements including Array configuration, method of arraying, correlation algorithm used for obtaining the combining weights and results of tianwen-1 mission are presented.

1. Introduction

Tianwen-1 is China's first independent Mars exploration mission, launched on July 23, 2020. The mission consists of an orbiter, a lander, and a rover named Zhurong. It aims to achieve comprehensive scientific exploration of Mars, including studying the planet's morphology, geology, soil characteristics, water-ice distribution, atmosphere, and space environment. On May 15, 2021, the lander and rover successfully touched down on the Martian surface, making China the second country to achieve a soft landing and deploy a rover on Mars. Tianwen-1 represents a significant milestone in China's deep space exploration program and contributes valuable data to global planetary science research. In order to acquire more scientific data, the National Astronomical Observatories, Chinese Academy of Sciences(NAOC), the responsible institution for the ground application system(GRAS) of the Tianwen-1 mission, has employed an antenna arraying to receive the downlink scientific data from the spacecraft.

2. Arraying Configuration

The antenna array consists of four antennas located at three ground stations under the NAOC. Among them, the Miyun Ground Station, situated in Bulaotun Town, Miyun District, Beijing, is equipped with two large-aperture antennas: GRAS-1 and GRAS-3. The GRAS-1 antenna has a diameter of 50 meters and is a wheel-track alt-azimuth prime-focus antenna, completed in 2006. The GRAS-3 antenna has a diameter of 40 meters and is a turntable alt-azimuth Cassegrain antenna, completed in 2016. The Kunming Ground Station, located on Fenghuang Mountain in the eastern suburbs of Kunming City, Yunnan Province in southwestern China, is equipped with one GRAS-2 antenna. The GRAS-2 antenna has a diameter of 40 meters and is a turntable alt-azimuth Cassegrain antenna, completed in 2006. The Wuqing Ground Station, located in Daliang Town, Wuqing District, Tianjin, is equipped with one GRAS-4 antenna. The GRAS-4 antenna has a diameter of 70 meters and is a wheel-track alt-azimuth Cassegrain antenna, completed in 2020. The signals received by each antenna are frequency-converted, sampled, digitized, and then transmitted via a dedicated fiber-optic network to the data processing center at the NAOC headquarters on Datun Road, Chaoyang District, Beijing, for combination and demodulation. The geographical distribution of the four antennas and the data center is illustrated in figure 1.

Figure 1. The geographical distribution of antenna arraying.

3. Method of Arraying

3.1 Ground Station Equipment Description

The signal transmitted by the spacecraft is received and amplified by the ground station antenna, then converted by a down-converter into an intermediate frequency (IF) analog signal at 70MHz. This IF analog signal is sampled and processed by a data acquisition system, generating zero-IF 8-bit IQ data, which is then transmitted via a network to the data processing center for signal combining. Both the down-converter and the data acquisition system are synchronized using a 10MHz frequency reference provided by the station's atomic clock. Major components of the Ground Station Equipment are illustrated in figure 2.

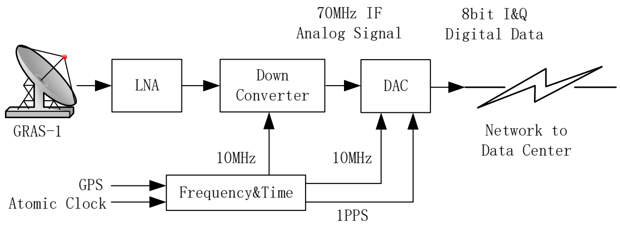

Figure 2. Ground station equipment for antenna array.

3.2 Method and Data Processing of Arraying

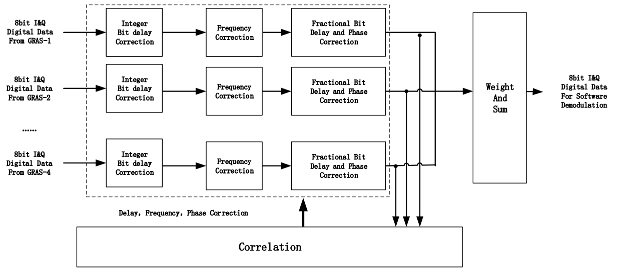

Figure 3. Antenna array and the combining flow diagram.

There are five fundamental signal-processing schemes for antenna arraying(1) Full-Spectrum Combining (FSC), (2) Complex-Symbol Combining (CSC), (3) Symbol-Stream Combining (SSC), (4) Baseband Combining (BC), and (5) Carrier Arraying (CA). Four of these schemes (CSC, SSC, BC, and CA) are effective only with signals exhibiting well-defined modulation characteristics, leveraging the unique spectral properties of the signal source. The Full-Spectrum Combining (FSC) method offers higher combining efficiency and is also effective for unknown or noise-like signals[1].In our array, The FSC method are used to combine the signals from four antennas. The block diagram of Data Processing is shown in figure 3. The 8bit IQ digital data from each antenna must be properly delayed and phase adjusted before combining. Precise values of the delay, frequency and phase are accomplished by correlating the signal streams[2]. The Interference fringes and cross-correlation phase spectrum before and after delay and phase correction are showed in figure 4 and figure 5.

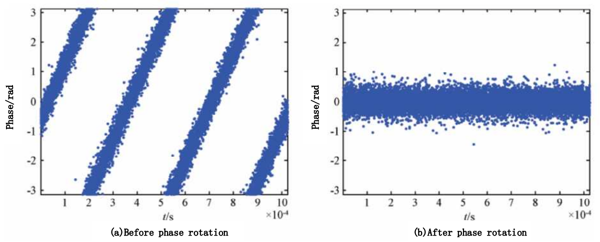

Figure 4. Interference fringes before and after phase rotation

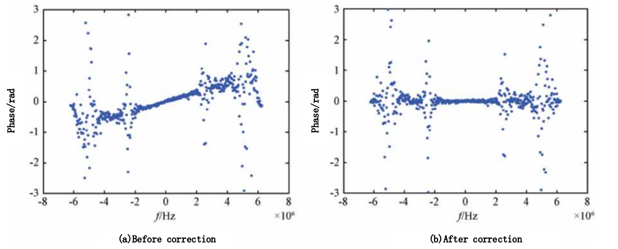

Figure 5. Cross-correlation phase spectrum before and after fractional delay correction

4. Correlation Algorithms

According to the configuration of array, the effective aperture of GRAS-4 antenna is much bigger the other antennas. SIMPLE algorithm is used to determine the phase and delay offsets between the array antennas. The Simple algorithm is diagramed in figure 6.

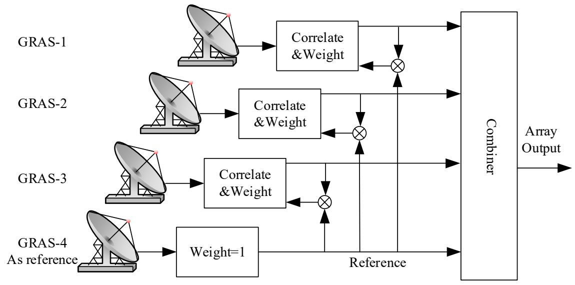

Figure 6. Diagram for the Simple method of combining.

The GRAS-4 antenna is designated as the reference antenna. The signals from the remaining antennas (GRAS-1/2/3) are correlated with the GRAS-4 signal to determine the residual delay and phase. These values are then used to correct the individual antenna signals, ensuring they achieve phase and delay coherence with the reference antenna signal.

5. Results

Figure 7 shows results from an array of maximum configuration. Four Antennas(GRAS-1/2/3/4) for X-band are employed to conduct track with the Tianwen-1 spacecraft in 12th,October 2021. Relative to the performance of the GRAS-4（70m） antenna, the array yielded a gain of 1.6 ± 0.1 dB. Theoretical improvement would have been 1.8 dB. The Combining efficiency is better than 95%. The variation in the SNR over time is attributable to the changing of antenna elevation. The reason why the GRAS-3（40m）antenna has a higher SNR than the GRAS-1(50m) antenna is that the GRAS-3 antenna is newer, with higher antenna efficiency and receiver sensitivity compared to the GRAS-1 antenna.

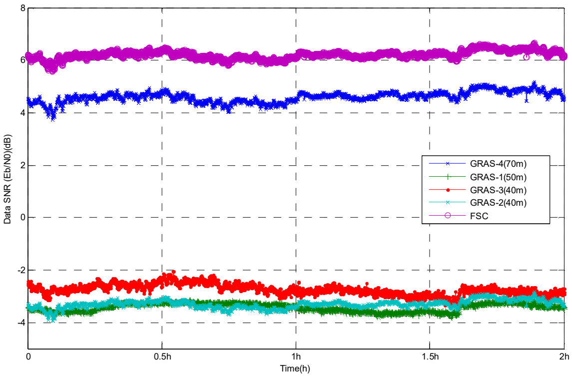

Figure 7. Four-antenna arraying with Tianwen-1 Mars Exploration Mission.

6. Acknowledgements

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References

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