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ScienceDirect

Advances in Space Research 58 (2016) 1638–1647

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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First geodetic VLBI sessions with the Chinese Deep Space Stations Jiamusi and Kashi

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Received 5 December 2015; received in revised form 14 July 2016; accepted 15 July 2016
Available online 25 July 2016

Abstract

The first three 24-h S/X dual-band geodetic VLBI sessions using two new Chinese Deep Space Stations (CDSSs), Jiamusi and Kashi, and four Chinese VLBI Stations (CVSs), Beijing, Kunming, Seshan, and Urumqi were conducted with the goal of improving the two CDSSs' positions, which were previously known to a few decimeters. Due to the limited frequency ranges of Jiamusi and Kashi, different but compatible frequencies for bandwidth synthesis were set at the CDSS and CVS stations. This paper presents the scheduling, correlation and fringe fit, and geodetic analysis of the observations. Final estimates of the station positions are obtained from the global solution using 5365 international VLBI sessions from August 3, 1979 through September 29, 2015. Position estimates for Jiamusi are accurate to 23, 35, and 41 mm in the X, Y, and Z directions, respectively, and for Kashi are accurate to 10, 20, and 16 mm. Precisions of the two CDSSs' positions are improved by a factor of 5–10 over previous values, which fully satisfies the requirements of the experiments and makes the first step towards the foundation and maintenance of the time–space reference frame based on the Chinese Deep Space Network (CDSN).

Keywords: VLBI; Chinese Deep Space Network; Station position determination; Terrestrial reference frame

1. Introduction

Very Long Baseline Interferometry (VLBI) now permits measurements of baseline lengths with accuracy better than cm-level (Schuh and Behrend, 2012; Sovers et al., 1998), and is one of the most important techniques that support the International Terrestrial Reference Frame (ITRF) (Altamimi et al., 2011; Böckmann et al., 2010). VLBI observations, combined with Satellite Laser Ranging (SLR), define the scale of the ITRF, and the latest contributions of VLBI to the ITRF consist of more than 5000 sessions involving more than 100 globally distributed stations (Bachmann et al., 2015). These international VLBI experiments are currently coordinated by the International VLBI Service for Geodesy and Astrometry (IVS; Schlüter and Behrend, 2007).

The VLBI baseline connects the reference points of two antennas; therefore, the coordinates of the antenna (i.e., the station position) at one end of the baseline can be precisely determined relative to the antenna at the opposite end. In addition, the antenna reference points of co-location stations can also be determined using local geodetic surveys and the Global Positioning System (GPS) (Lösler, 2008, 2009). However, since potential systematic biases between different space geodetic techniques may distort the measured results (Boucher et al., 2015; Petrov et al., 2009), the most effective method for determining VLBI station position is to conduct dedicated geodetic VLBI experiments. And another advantage of this approach is that the VLBI measurements also provide useful diagnostics on the VLBI equipment (Petrov et al., 2011).

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http://dx.doi.org/10.1016/j.asr.2016.07.022
0273-1177/

In 2013, as part of the Chinese Deep Space Network (CDSN), the Jiamusi antenna located in Northeastern China and the Kashi antenna located in Northwestern China were deployed for deep space navigation and communication. According to the plan for future Chinese deep space missions, these two Chinese Deep Space Stations (CDSSs) are expected to join the VLBI observation network to track spacecraft, and accurate station positions would become a necessity for precise deep space navigation. Therefore, it is urgent to conduct geodetic VLBI observations using the CDSS stations and Chinese VLBI Stations (CVSs; Li et al., 2008), which is also the first step towards the foundation and maintenance of the time–space reference frame based on the CDSN.

The first fringes between Jiamusi and Kashi were obtained during an experiment tracking the Venus Express in April 2013 (Han et al., 2014). This prompted the first three 24-h S/X dual-band geodetic VLBI sessions using the two CDSSs on September 28, 2014, January 22, 2015, and March 21, 2015, which aimed to measure their positions with accuracy better than 50 mm. This paper reports the results of the geodetic VLBI sessions using Jiamusi, Kashi, and four CVSs, Beijing, Kunming, Seshan, and Urumqi. The technical details of the two CDSSs are provided in Section 2. Section 3 presents the frequency setting and schedule design. In Section 4, we describe the strategies for correlation and fringe fit. The geodetic analysis and results are presented in Section 5. The final section summarizes the conclusions of the study.

2. Antennas

Both the Jiamusi and Kashi antennas are of a beam waveguide design with a movable sub-reflector, whose position can be changed to compensate for the deformation of the antenna at different elevations. On an azimuth–elevation mount, the parabolic reflector has an aperture of 66 m for Jiamusi and 35 m for Kashi. The platform holding the sub-reflector is supported by a quadripod, as shown in Fig. 1(a) and (b). Antenna drawings are shown in Fig. 1 (c) and (d), in which the heights of the concrete foundation *h*f, the pillar *h*p, the vertex *h*v, and the subreflector *h*s are given; this information can be utilized for computation of thermal variations (Wresnik et al., 2007). The beam waveguide schemes for Jiamusi and Kashi are also illustrated in Fig. 1(c) and (d), respectively. It is worth mentioning that Kashi can function not only on the S and X frequency bands, but also the Ka band, in the frequency range 31.8–32.3 GHz. The root mean square (RMS) of the parabolic reflector surface of Kashi is less than 0.3 mm. There are two Ka band horns in Kashi; the lower one is for receiving signals, whereas the higher one is for transmitting signals.

The S/X band receivers in Jiamusi and Kashi have frequency ranges of 2200–2300 MHz and 8400–8500 MHz, whereas the CVS receivers have a much wider frequency range. Local oscillators (LOs) with frequencies of 1930 MHz and 8130 MHz are used to down-convert the S/X radio frequency (RF) signals to an intermediate frequency (IF) band of 320 MHz. The IF signals are then input into a digital base band converter (DBBC), which performs signal conditioning, digital sampling, baseband conversion, and data formatting. The output format of the DBBC depends on its working mode: either astronomy or spacecraft navigation. In the astronomy mode, the international VLBI standard interface (VSI) is utilized and the raw data are recorded to disk in Mark5B format. The temperature of the S/X band low noise amplifier (LNA) of Jiamusi is 11/18 K, and of Kashi 18/18 K.

Measurements of the system temperature are obtained using the Y-factor method, which is also utilized for the antenna efficiency, gain, and system equivalent flux density (SEFD) measurements. For instance, the SEFD is determined by measuring the power on and off a source with a calibrated flux density based on

$$\mathrm{SEFD} = \frac{S}{(Y-1)\cdot K_1\cdot K_2\cdot K_3\cdot K_4\cdot K_5} \quad (1)$$

where S is the flux of the source at certain time and frequency, Y is the ratio of the power on and off a source, and K_{1-5} denote the calibrations for the source flux induced by the atmosphere, source structure extension, time, frequency, and polarization. The uncertainty of the measured SEFD can be estimated by

$$\left(\frac{\Delta\mathrm{SEFD}}{\mathrm{SEFD}}\right)^2 = \left(\frac{\Delta S}{S}\right)^2 + \left(\frac{\Delta Y}{Y-1}\right)^2 + \sum_{i=1}^{5}\left(\frac{\Delta K_i}{K_i}\right)^2 \quad (2)$$

where ΔX denotes the uncertainty of X. The sources utilized for the SEFD measurements of Jiamusi and Kashi are Cygnus A and Cassiopea A, respectively. The measured S/X SEFD of Jiamusi is 68/90 Jy, and of Kashi is 341/291 Jy. The measurements are taken at 2250/8450 MHz of right-handed circular polarization, and at S/X elevation of 35°/30° for Jiamusi and 87°/27° for Kashi. Note that the SEFD of Jiamusi is much smaller than that of Kashi as a consequence of its much larger aperture. To evaluate the SEFD uncertainty, the uncertainty of the Y-factor is set to 0.05 dB and the relative uncertainty of the calibrated source flux (i.e., S/K_{1-5}) is set to 2%.

The primary specifications of Jiamusi and Kashi are summarized in Table 1. Note that the antenna gain of Jiamusi is about 5 dB higher than Kashi, benefiting from its large aperture but at the cost of the slewing rate. The high antenna efficiency of Kashi indicates that the antenna is effectively designed and constructed, whereas the efficiency of Jiamusi in the X band is comparatively small. For the specifications of the CVS stations, please refer to Li et al. (2008), Zhang et al. (2009), and Hao et al. (2010).

3. Scheduling

Six stations were involved in the three geodetic VLBI sessions, named cdsn01–cdsn03. The cdsn01 session was