The XF-Type Correlator for Delta-DOR in Deep Space Navigation

Maoli Ma[1,2], Weimin Zheng[1], Yidan Huang[1], Guangli Wang[1]

Abstract The Delta-DOR technique provides high-precision angular position data for the Chinese Chang'E-3 satellite. The standard DOR tones are comprised of several single-frequency signals that are spaced several MHz or several tens of MHz apart. The correlator in China is of FX type. It is suitable for quasars with a flat spectrum, while the spectral resolution limits the accuracy of the phase from the satellite. Or the DOR tones must have harmonics that share energy, but it is useless for SNR and measurement precision. We report on the XF correlator, which is a tailor-made correlator for single-frequency signals.

Keywords Delta-DOR, Delta-VLBI, correlator

1 Introduction

Delta-DOR (Delta Differential One-Way Ranging) is a Very Long Baseline Interferometry (VLBI) technique that can be used in conjunction with Doppler and ranging to improve spacecraft navigation by more efficiently determining spacecraft angular position in the plane of sky. The standard DOR tones are comprised of several single frequency signals (Figure 1). A narrow tone spacing is required for integer cycle phase ambiguity resolution, while a wider tone spacing is required for high measurement accuracy [1]. It is quite different from quasars with a flat spectrum. The Chinese correlator is of FX type. It is suitable for quasars, while in order to distinguish single frequency signals, a high FFT resolution is required, especially for weak signals, and the FFT resolution limits the accuracy of the phase from the satellite.

The DOR tones in China are not a single-frequency signal as the standard ones. They have harmonics with certain bandwidths. These harmonics will share the total limited energy with the DOR tones, while they do not improve the precision of the tone phase. If all total energy is given to the DOR tones, the higher SNR will improve the precision of the tone phase.

NASA and ESA have already developed special correlators for DOR tones [1, 2]. We report on an XF-type correlator, which is tailored for single frequency signals. The definition of Delta-DOR we got is different from the one (we call Delta-VLBI) in China. We discuss the transformation of Delta-VLBI and Delta-DOR.The reliability of Delta-DOR is further validated.

1. Shanghai Astronomical Observatory, CAS
2. University of Chinese Academy of Sciences

2 Delta-VLBI and Delta-DOR

Although Delta-DOR is a VLBI technique, the geometric delay definition of Delta-DOR at NASA and ESA is different from the traditional Delta-VLBI. Delta-VLBI measures the geometric time delay when the same wave front of a signal reaches two geographically separated stations (Figure 1).

$$\tau_{VLBI} = \frac{r_1 - r_2'}{c} = t_1 - t_0. \tag{1}$$

For Delta-DOR, two VLBI stations receive radio signals at the same time and the difference of the transmission times is measured (Figure 2).

$$\tau_{DOR} = \frac{r_1 - r_2}{c} = t_2 - t. \tag{2}$$

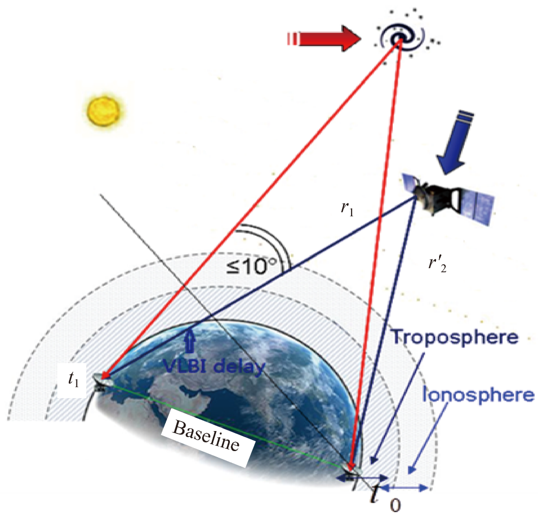

Fig. 1 Geometric principle of Delta-VLBI.

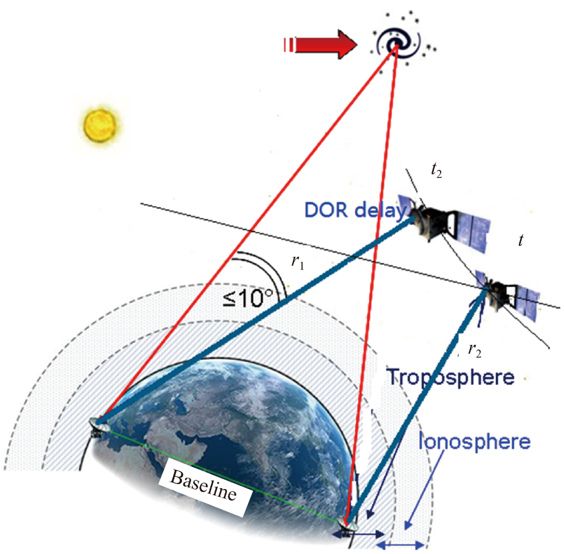

Fig. 2 Geometric principle of Delta-DOR.

There is a relationship [3] between them:

$$c \cdot \tau_{VLBI} = c \cdot \tau_{DOR} + \frac{\partial r_2}{\partial t} \tau. \tag{3}$$

3 XF Correlator in s1404a

s1404a is an experiment about China CE2 satellite. The sample rate is 16 Mbps/s, bandwidth 8 MHz, and quantization 1 bit. We processed data from the Shanghai 25-m (Sh), Kunming 40-m (Km), and Urumchi 25-m (Ur) antennas. Figure 3 shows the DOR tones distribution. DOR1 and DOR4 are wider tones for high accuracy; DOR3 is one of the narrow tones used in conjunction with the main carrier to resolve ambiguity. Figure 4 depicts the spectrums of the main carrier for Sh–Km–Ur. The signal at Ur is nearly 7 dB weaker than for Sh and Km. The other eight signals with frequency exactly .9 MHz and 1 MHz interval are phase calibration signals (pcals). The power of the main carrier is larger than the pcal, while the DOR tones are much weaker than the pcals.

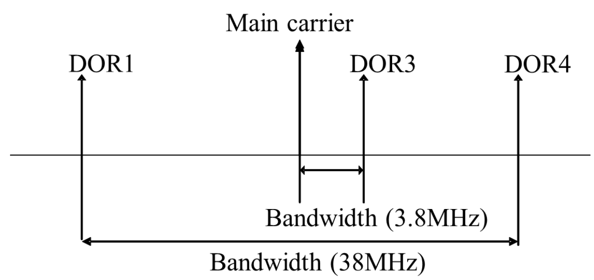

Fig. 3 DOR signal distribution in s1404a.

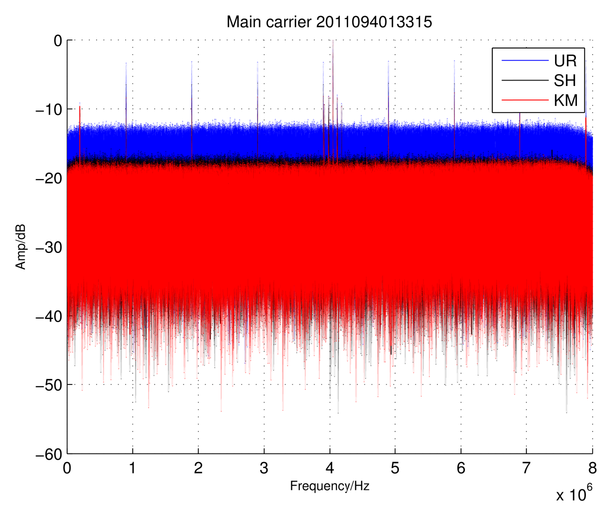

Fig. 4 Spectrums of main carrier. Blue is Ur, black is Sh, and red is Km.

A dynamical model will be used for the phase rotation on the raw data. At NASA and ESA, DOR is a one-way range. There is no uplink, and the satellite directly transmits the signal to the receiving station. In

China, on the other hand, the satellite first locks signal to the uplink station and then re-transmits to the VLBI station. In s1404a, the uplink station was Kashi. The dynamical model must include the uplink light time in addition to the downlink time. After rotation, a signal with low frequency is received. In order to decrease jamming signals and computation, the signal is filtered and downsampled to 100 Hz. Then we do the correlation in the time domain. The signal after correlation is also around 0. A low sample number is enough for FFT. The residual frequency and phase will be estimated in the frequency domain. The quasar's phase and delay is used to correct for system errors, the atmosphere, and the ionosphere. The quasar data, atmosphere, and ionosphere are from the VLBI Center of the Shanghai Astronomical Observatory (SHAO). Figure 5 shows a flow chart of the XF correlator.

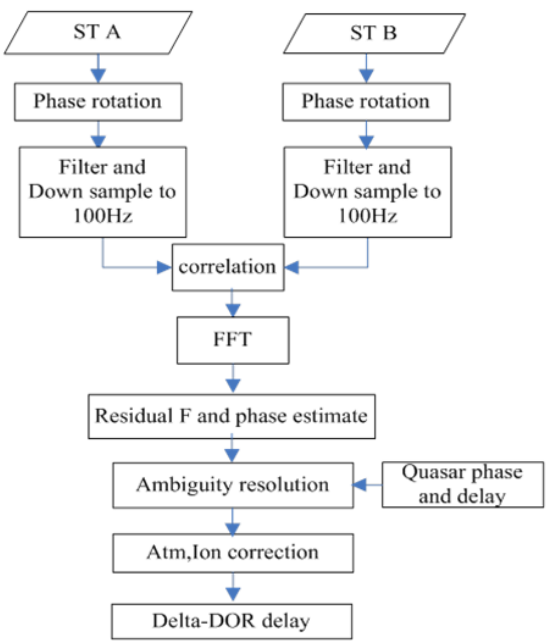

Fig. 5 Flow chart of the XF correlator.

4 Results

In order to confirm our Delta-DOR results, we compared them to Delta-VLBI from the VLBI Center. There is a significant difference because of the different definitions of Delta-DOR and Delta-VLBI (see the upper panel in Fig. 6). They are consistently below 0.3 ns and within the error limit (Table 1) after we corrected the difference with Equation (3). Table 1 lists the residuals of Delta-VLBI and Delta-DO from the XF correlator. For Sh–Km, they are about 0.34 ns for both Delta-VLBI and Delta-DOR. For Sh–Ur and Km–Ur, the errors are much larger because of the lower SNR for Ur.

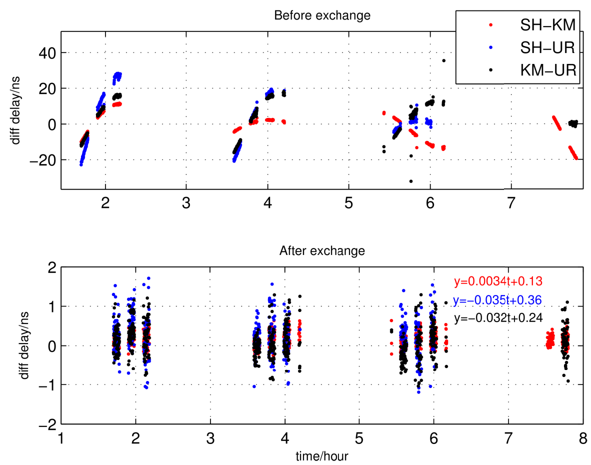

Fig. 6 Difference between Delta-DOR and Delta-VLBI.

Table 1 Residuals of Delta-VLBI and Delta-DOR.

	Sh–Km	Sh–Ur	Km–Ur
Delta-VLBI	0.34	0.9	0.76
Delta-DOR	0.34	0.91	0.8

We also compared the closure delay of the above three baselines about Delta-DOR and Delta-VLBI (Figure 7). They are at about the same level.

5 Future Plans

In this paper, the DOR is three-way, and a dynamical model including uplink is considered. We intend to process one-way DOR in the future, where the frequency shift of ultra-stable crystal oscillator must be considered. We will also analyze each error, such as instrumental errors, clock jitters, and transmission medium errors in Delta-DOR.

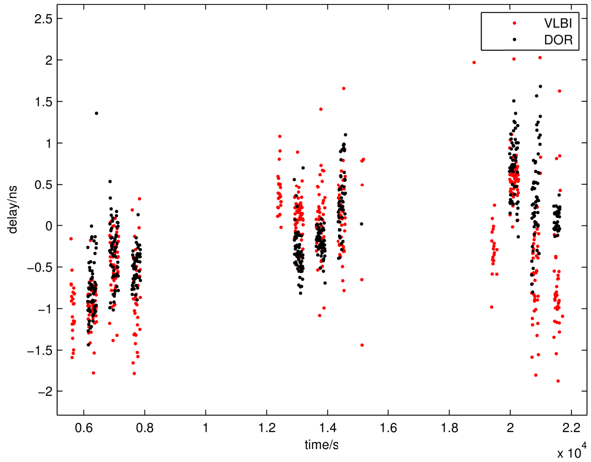

Fig. 7 Closure delay about Delta-DOR and Delta-VLBI.

Acknowledgements

The work was supported by the Opening Project of Shanghai Key Laboratory of the Space Navigation and Position Techniques (No. Y224351002) and NSFC (No. Y247041001, Y347471001).

I'm very grateful to Professor Luciano Iess for providing a nearly two-months learning opportunity at Radio Science Laboratory, Sapienza University of Rome. Thanks to Francesco Barbaglio and Alessandro Ardito for the disscussions on Delta-DOR.

References

1. J. S. Border and J. A. Koukos, Technical Characteristics and Accuracy Capabilities of Delta Differential One-Way Ranging (ΔDOR) as a Spacecraft Navigation Tool, CCSDS Meeting of RF and Modulation Standards Working Group, Munich, Germany, 09/20/1993.
2. L. Iess, R. Abello, A. Ardito et al., The European ΔDOR correlator, 57th International Astronautical Congress, Valencia, 2–6 October 2006 (IAC-06-B3.1.05).
3. Yong Huang, Orbit Determination of the First Chinese Lunar Exploration Spacecraft CE-1.