The XF type correlator for Delta-DOR in deep space navigation

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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. DOR tones are comprised of several single frequency signals(Fig.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's quite different from quasar with flat spectrum. The domestic correlator is FX type. It is suitable for quasar, while in order to distinguish single frequency signal, a high FFT resolution is required, especially for weak signal. It costs a lot in computer, while the output is mostly noise. NASA and ESA have already developed special correlator for DOR tones[1,2]. We'll report an XF type correlator, which is tailor-made for single frequency signal. The definition of Delta-DOR we got is different from the one(we called Delta-VLBI) in China. We'll discuss the transformation of Delta-VLBI and Delta-DOR.The reliability of Delta-DOR is further validated.

Delta-VLBI and Delta-DOR

Though Delta-DOR is a VLBI technique, the geometric delay definition of Delta-DOR from NASA and ESA is different from traditional Delta-VLBI.

Delta-VLBI will measure the geometric time delay when the same wave front of signal reaching at two geographically separated stations(Fig.1).

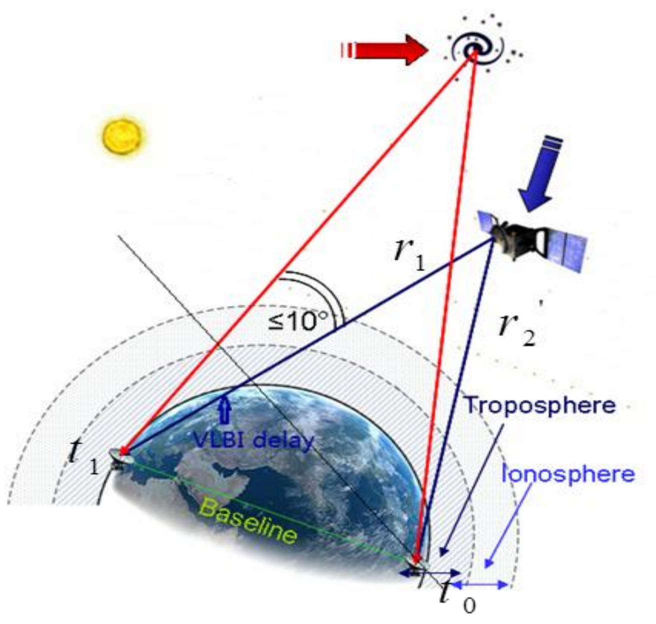

Fig.1 Geometric principle of Delta-VLBI

$$\tau_{VLBI} = \left(r_1 - r_2'\right)/c = t_1 - t_0 \qquad (1)$$

For Delta-DOR, the two different VLBI station will receive radio signals at the same time, the different transmitted time will be measured(Fig.2).

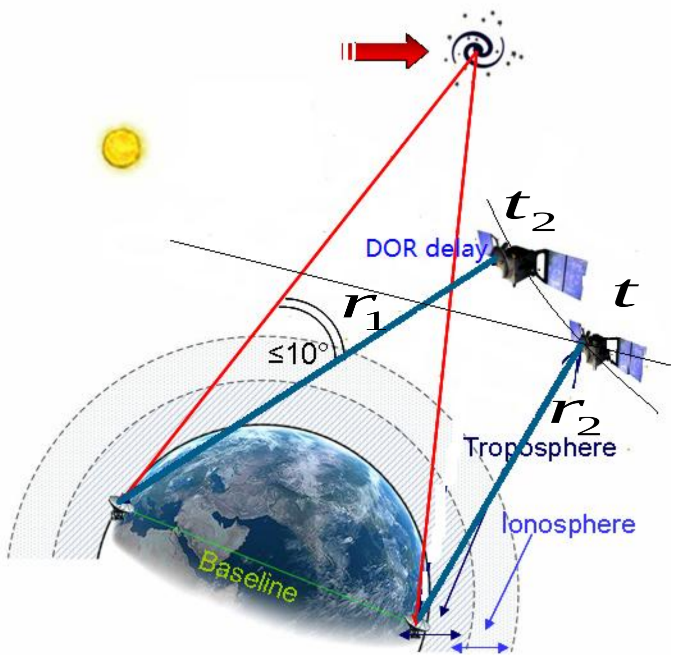

Fig.2 Geometric principle of Delta-DOR

$$\tau_{DOR} = \left(r_1 - r_2\right)/c = t_2 - t \qquad (2)$$

There is a relationship[3] between then,

$$c\tau_{VLBI} = c\tau_{DOR} + \frac{dr_2}{dt}\tau \qquad (3)$$

XF correlator on s1404a

s1404a is an experiment about China CE2 satellite. The sample rate is 16Mbps/s, bandwidth 8MHz, quantization 1 bit. We processed data from Shanghai(SH 25m), Kunming(KM 40m), Urumchi(UR 25m). Fig.3 is the DOR tones distribution. DOR1 and DOR4 and wider tone for high accuracy, DOR3 is one of the narrow tone, conjunction with main carrier to resolve ambiguity. Fig.4 is the spectrums of main carrier for SH，KM，UR. The signal from UR is nearly 7dB weaker than SH and KM.

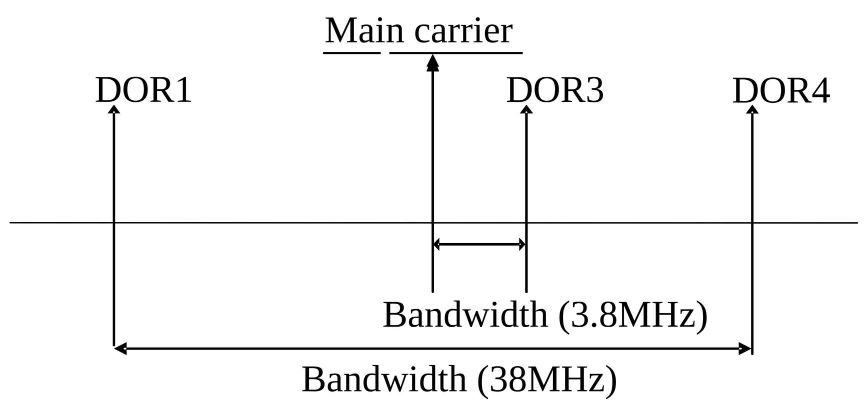

Fig.3 DOR signal distribution in s1403a

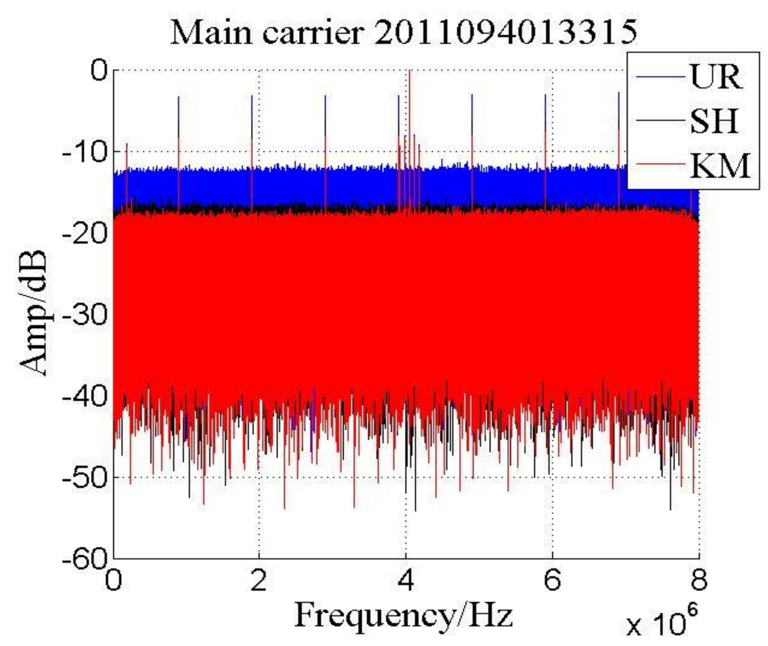

Fig.4 Spectrums of main carrier. Blue is UR, black is SH and red is KM.

A dynamical model will be used for phase rotation on the raw data. In NASA and ESA, DOR is one-way range. There is no uplink, and the satellite will directly transmit signal to received station. While in China, the satellite will lock signal from uplink station first, then retransmit to VLBI station. In s1403a, the uplink station is Kashi. The dynamical model must include uplink light time beside downlink's.

After rotation, a signal with low frequency will be got. In order to decrease jamming signals and computation, the signal will be filtered and down sample to 100Hz. Then we'll correlate then in the time domain. The signal after correlation is also around 0. In Fig.6, The red and blue are signals from KM and UR after phase rotation with frequency around 10Hz. The black is signal after correlation with frequency around 0, and the bandwidth of those signals is 100Hz. A low sample number is enough for FFT. The residual frequency and phase will be estimated in frequency domain. Quasar's phase and delay will be used to correct system error, atmosphere and ionosphere errors. The data of quasar, atmosphere and ionosphere is from VLBI center in Shanghai Astronomical Observatory(SHAO). Fig.5 is the flow chart of XF correlator.

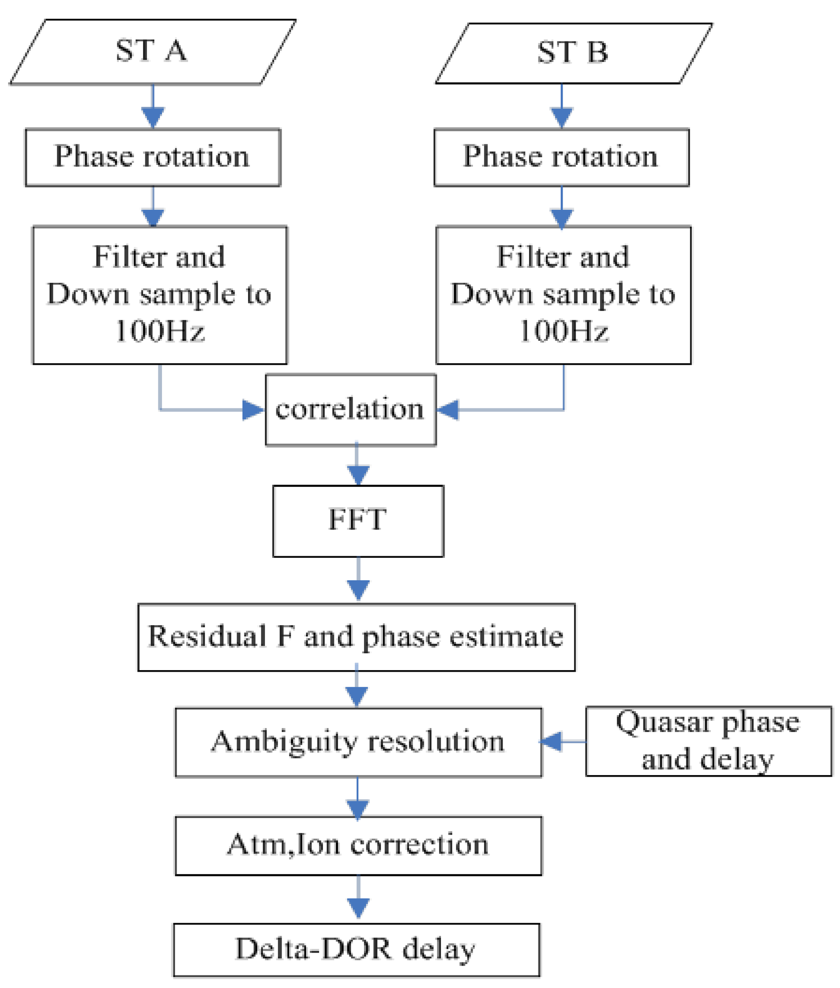

Fig.5 The flow chart of XF correlator

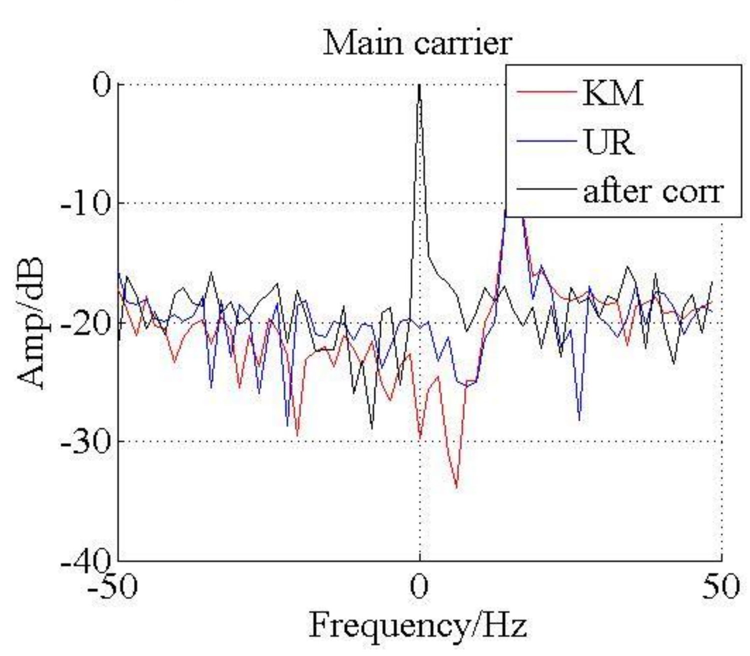

Fig.6 The red and blue are signals from KM and UR after phase rotation, the black is signal after correlation.

Results

In order to confirm Delta-DOR we get, we'll compare with Delta-VLBI from VLBI center. There's a significant difference because of the different definition of Delta-DOR and Delta-VLBI(see the upper in Fig.7). While they're consistent in 0.3ns within the error limit(Table 1) after we corrected the difference with formula 3.

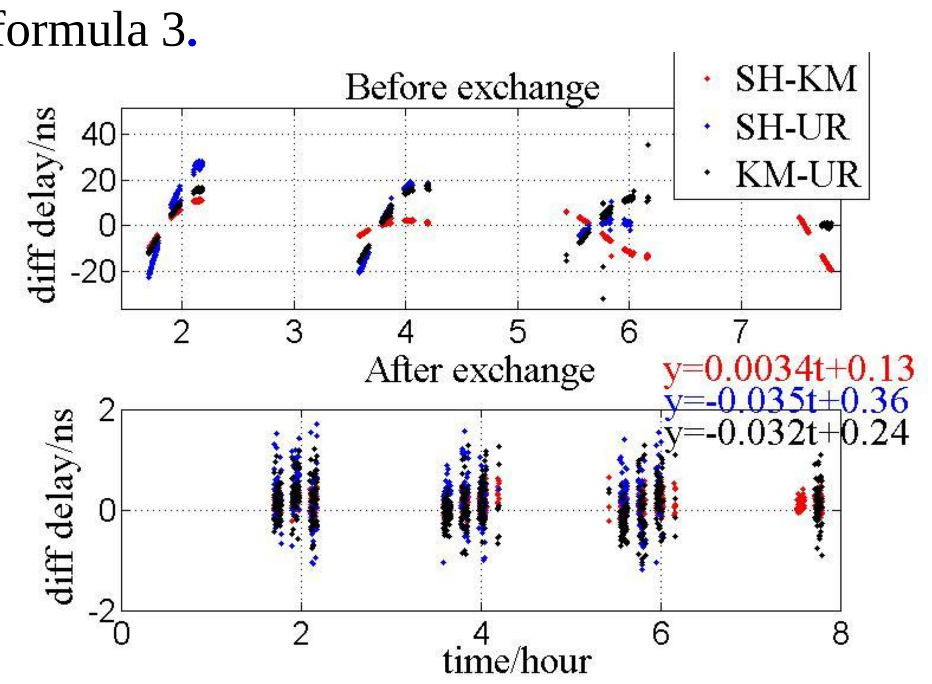

Fig.7 Difference between Delta-DOR and Delta-VLBI

Table 1 is the residuals of Delta-VLBI and Delta-DOR from XF correlator. For SH-KM, they're about 0.34ns for both Delta-VLBI and Delta-DOR. For SH-UR and KM-UR, the errors are much larger because of the lower SNB of UR.

Table 1 Residuals of Delta-VLBI and Delta-DOR

	SH-KM	SH-UR	KM-UR
VLBI	0.34	0.9	0.76
DOR	0.34	0.91	0.8

We also compared the close delay of the above three baseline about Delta-DOR and Delta-VLBI(Fig.8). They're closed in the same level.

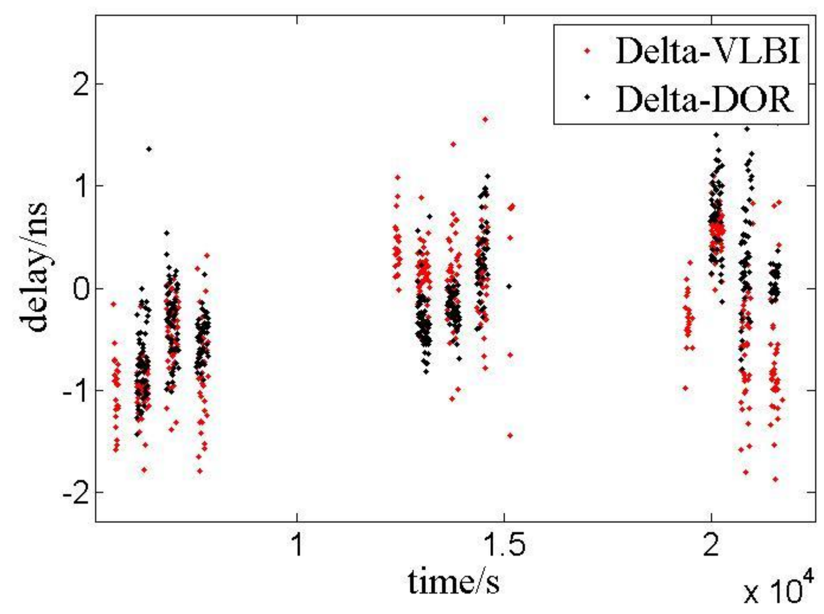

Fig.8 Close delay about Delta-DOR and Delta-VLBI

Future plans

In this poster, the DOR is three-way, and a dynamical model including uplink is considered. We'll process one-way DOR in the future, where the frequency shift of ultrastable crystal oscillator must be considered. We'll also analyse each error, such as instrument error, clock jitter, transmission medium error in Delta-DOR.

Acknowledgments

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References

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