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Simultaneous Dual Frequency VLBI Observation Using VERA

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Abstract

We report the first simultaneous dual beam, dual frequency VLBI experiment using VLBI Exploration Radio Astronomy (VERA). The aim of this experiment is to demonstrate the feasibility of the simultaneous multi-frequency phase referencing using VERA and the upcoming Korean VLBI Network (KVN). This multi-frequency phase referencing is based on the idea that the differential atmospheric phase delay is mainly caused by the differential water-vapor-induced excess path length in the troposphere. The technique takes advantage of the non-dispersive nature of the water-vapor-induced phase delay. Our VERA observation was conducted on 15th April 2005 between 14:15 and 21:30 (UT). At 22GHz (Beam A), NRAO512 and at 43GHz (Beam B), a bright quasar 3C345, which is only 0.5 degree apart from NRAO512, were observed simultaneously. Different from the conventional frequency switching phase referencing observation, radio signals from two quasars were recorded simultaneously. This simultaneous observation ensures that the phase delay solution interval problem, which could be severe in the conventinal method, does not exist in our case.

1. Introduction

In the high radio frequency VLBI observation, it is well known that the long-term phase noise, typically of time scales longer than several seconds, is dominated by the tropospheric fluctuation, more precisely of water-vapor content(Rogers et al. 1984; Asaki et al. 1996; Sasao 2003). Since this fluctuation has non-dispersive nature, i.e. $\propto \nu$, it is a serious hindrance of the high frequency VLBI observation. In order to get rid of this hindrance, various phase referencing techniques are suggested. The basic idea behind the various phase referencing techniques is literally to refer to the phase of another (stronger) source(s). At mm wavelength, the phase variation due to the fluctuation is often so extreme that the phase changes more than π radian in a few tens of seconds (e.g. in Fig. 1). That means the target source and the phase reference source should be observed at the same time for effective phase referencing. VLBI Exploration Radio Astronomy (VERA) is the VLBI facility dedicated to high accuracy astrometry ($\sim 10\mu$arcsec) adopting the simultaneous phase referencing (Kobayashi et al. 2003). VERA has a unique dual beam system for simultaneous phase referencing (Kawaguchi et al. 2000). The phase referencing feasibility of VERA is well demonstrated by Honma et al. (2003) at 22GHz.

The aim of this experiment is to test and to demonstrate the feasiblilty of the simultaenous multi-frequency phase referencing using VERA. The experiment is designed to demonstrate that VERA could do 'phase reference', not only between two sources at the same frequencies, e.g. at 22GHz ('single-dual'), but that it is also feasible between two sources at two different frequency such as 22GHz and 43GHz ('double-dual'). At higher frequency, in general, the receiver performance becomes worse, the aforementioned atmospheric fluctuation increases with $\propto \nu$, and the source flux decreases. These altogether lead to a rapidly decreasing number of the possible phase reference sources at mm wavelength. Therefore phase referencing to a lower frequency is of general interest for mm VLBI research. For that reason, the frequency switching phase referencing is tested (e.g. Middelberg et al. 2005). However, considering the rapid phase change at mm wavelength, the simultaneous observation, such as this 'double-dual', is favorable.

2. Korean VLBI Network

KVN is the first VLBI facility in Korea and is the first dedicated mm VLBI facility in the world. KVN is designed for simultaneous multi-frequency observation (Minh et al. 2003; Kim et al. 2004). Using the simultaneous, multi-frequency phase referencing, KVN is expected to provide precise astrometric information at wide radio frequency range, from 22GHz up to 129GHz (Minh et al. 2003; Kim et al. 2004). The precise positional information of celestial objects at wide range of radio frequency is invaluable in various astrophysical and also in interdisciplinary contexts (e.g. Lobanov 1998; Philips et al. 2003; Schlueter & Vandenberg 2003; Middelberg et al. 2005). This and another important goal, sensitive multi-band VLBI imaging through long integration time, will be done by simultaneous multi-frequency observation. At mm wavelength, due to the known limitations (Section 1), the multi-frequency phase referencing (i.e. self-phase referencing) seems to be more promising than the other methods (Sasao 2003). The KVN beam transporting system employs frequency selective surface lowpass filters (LPFs) (Kim et al. 2004 and reference therein). KVN is under construction and plans to begin its test observation in 2007/08.

3. Observation

The VERA observation was done on 15th April 2005 [UT 14:15-21:30]. The 'double-dual' mode was configured as below. With the beam A we observed NRAO512 at 22GHz, a bright BL Lac object. With the beam B at 43GHz, an even brighter quasar 3C345, which is only 0.5 degree apart from NRAO512, was observed simultaneously. 128MHz broadband mode with 250KHz channel width (512 channels) was taken and single LL circular polarization mode was used. At each station, data was recorded on tapes and delivered to Mitaka correlation center of National Astronomical Observatory, Japan.

4. Data Reduction

After the instrumental phase calibration, the residual phase delay solutions were obtained. At the shortest baseline, Mizusawa-Iriki baseline, the solutions are most stable (Fig. 1). At the longer baselines, e.g. Miz.-Ogasawara, Miz.-Ishigaki, the phases change more rapidly. In order to test the feasibility of the phase transfer between two frequencies, the correlation coefficients were estimated. It was done at the time range where the phase changes are rather moderate. The correlation coefficients with various solution intervals, i.e. 20/30/60 seconds, are compared. High positive values are obtained from Miz.-Iri. & Miz.-Oga. baselines (> 0.9). At the longest baseline, Miz-Ish., weak anti-correlation is seen. This is due to n*pi ambiguity in the phase solutions. It increases with baseline length and with water vapor in the atmosphere. It is clearly shown that , n*pi ambiguity should be removed for successful phase transfer and for long integration time.

Fig. 2 and Fig. 3 show the trial n*pi ambiguity free phase soluion at 22 & 43GHz. Long-term, $\gg$ atmospheric coherence time, phase residual which is proportional to frequency is seen. It could be due to the error in the tracking-center psotions or the error in the station position (Honma et al. 2003). The analysis to remove this residual is being done. Together with the final phase referencing result, it will be presented elsewhere.

5. Atmospheric Phase Delay

The tropospheric excess path delay is largely non-dispersive over a wide range of radio frequencies. Asaki et al. (1998) demonstrate mm (146GHz) phase delay compensation through cm (19.5GHz) phase reference source with Pair-Antenna-Method; they observe two sources simultaneously at two frequencies. The Middelberg et al.(2005) experiment shows the feasibility of the 'fast frequency switching' method (14.5GHz & 86GHz); a source is observed at two frequencies in sequence. Though their methods could be argued to deliver spatially or timely incoherent phase compensation solutions, they could prove the non-dispersive nature of the path length delay and prove that sensitive mm VLBI imaging is achievable with multi-frequency phase referencing method (Asaki 1998; Middelberg et al. 2005). For astrometric purposes, however, the ionospheric phase delay which has dispersive nature, should be corrected (Middelberg et al. 2005), too. This correction has been done through GPS measured Total Electron Content (TEC), so far. Since the GPS signals do not come from the target source direction and GPS data are spatially very sparsely sampled, the modeled ionosphere is often not accurate enough for astrometric purposes. A more precise determination of the ionospheric influence can be obtained, if the group delay is obtained from the source direction at lower radio frequency. Further experiments including this idea will be made.

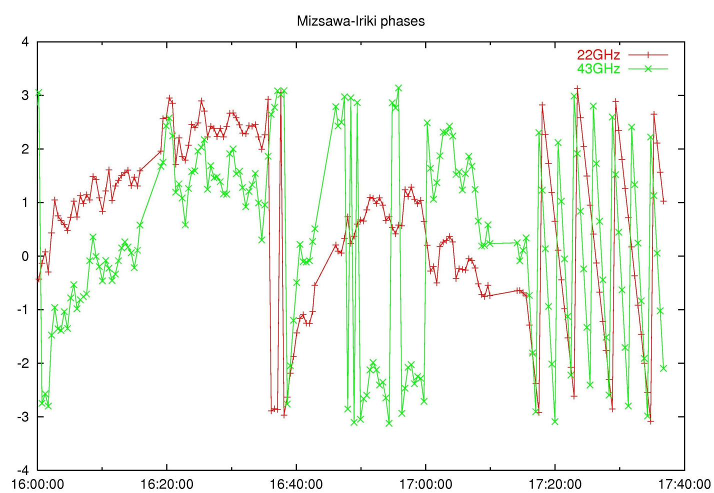

Figure 1. Phase solution of the first half of the observation after the instrumental calibration. Faster phase at 43GHz is visible. The faster phase rotation brings 2π ambiguity of 43GHz in the given time range. The phase rotation of the last 20 minutes is an artifact.

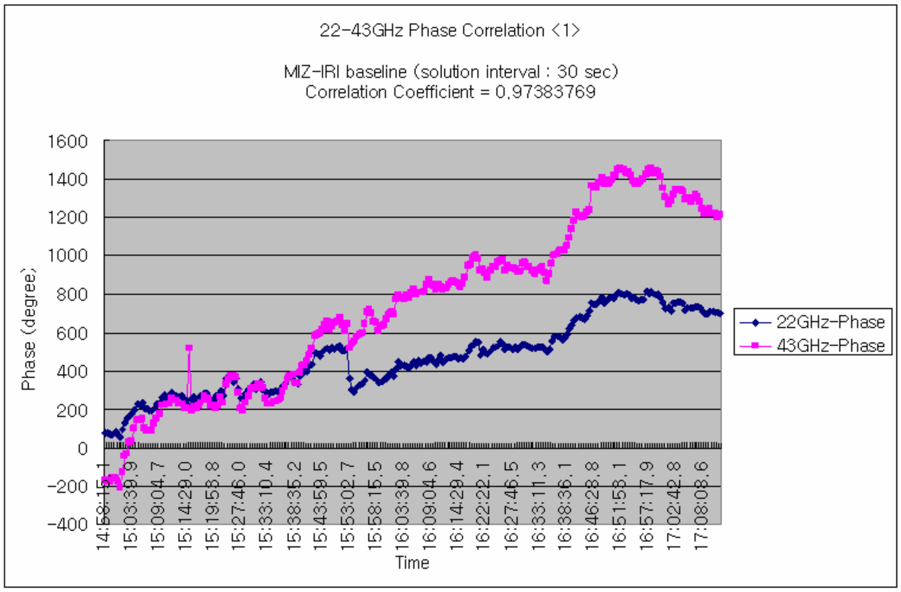

Figure 2. The phase solution of the first half of the observation after 2π ambiguity removal. Long-term increase of the phases which is obviously not from the atmosphere is seen.

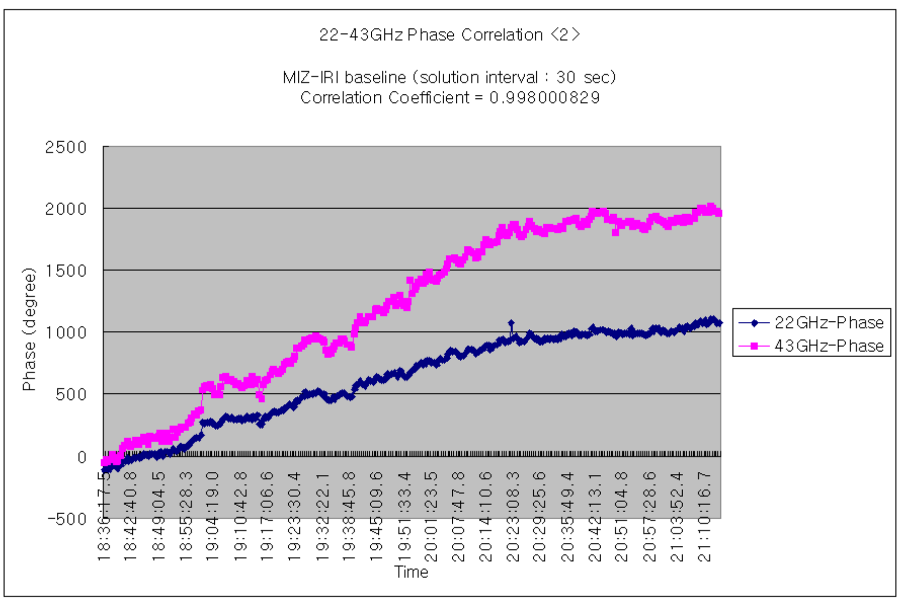

Figure 3. The phase solution of the second half of the observation after 2π ambiguity removal. The long-term non-atmospheric, but frequency-proportional increase of the phases is more clearly noticeable.

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