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First simultaneous 4-frequency phase referencing test for mm-VLBI observation

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We present the results of the first 4-frequency simultaneous VLBI fringe detection at 22, 43, 86, and 129 GHz with the Korean VLBI Network (KVN) along with a multi-frequency phase referencing (MFPR) test. The KVN employed a new multi-frequency receiver system that can observe four different radio bands (22/43/86/129 GHz) simultaneously. This system is expected to be an excellent tool to calibrate the atmospheric phase fluctuations by applying MFPR. 4-frequency simultaneous fringes of 3C279 at 22, 43, 86, and 129 GHz were first successfully detected on all three KVN baselines in April 2012. The tight correlation of fringe phases between the four frequencies is a clear indication of a non-dispersive characteristic of the neutral troposphere to the radio systems. A high signal-to-noise ratio fringe-detection of 3C279 at 129 GHz was obtained by referencing to the 22 GHz fringes. This initial experiment demonstrates the feasibility of MFPR as an effective way to overcome short coherence time in mm-VLBI.

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1. Introduction

The Korean VLBI Network (KVN) introduced a unique multi-frequency receiver system for simultaneous observations of four radio frequency bands (22/43/86/129 GHz) [1, 2]. This system is mainly designed for multi-frequency phase referencing (hereafter MFPR), a technique that uses the lower frequency fringe phase to compensate the phase at the higher frequencies, taking advantage that the fringe phases at lower frequency are more stable and have higher signal-to-noise ratio (SNR) than those at the higher frequencies. At mm wavelength, the performances of VLBI are significantly limited by the atmospheric phase fluctuations, causing a severe loss of coherence [3, 4, 5]. In order to reduce these atmospheric effects, phase referencing methods have been developed and widely used ([6] and references therein).

In particular, MFPR with a multi-frequency feed does not have a reference source problem or a loss of coherence due to the separation angle between the target and reference sources because the target source itself at lower frequency will be used as a reference to calibrate rapid atmospheric phase fluctuations at higher frequencies. The coherence time becomes shorter as the observing frequency increases because the phase fluctuations are proportional to the observing frequency. Therefore, MFPR with a multi-frequency feed can be an ideal technique for mm or submm VLBI that substantially suffers from severe loss of coherence. The first feasibility test of the MFPR technique between 22 and 43 GHz was demonstrated by Jung et al. [6]. In this paper, we present the results of the first 4-frequency simultaneous VLBI fringe detection and multi-frequency phase referencing test at 22, 43, 86, and 129 GHz with KVN.

2. First simultaneous 4-frequency VLBI fringes

The first simultaneous 4-frequency (22/43/86/129 GHz) VLBI fringes were obtained on the KVN Yonsei-Ulsan baseline on 2011 December 13. After installation of a 129 GHz receiver at Tamna station in March 2012, we successfully detected 4-frequency VLBI fringes on all KVN baselines for the first time (Fig. 1). The observation was carried out on 2011 April 7 with three KVN telescopes (Yonsei, Ulsan and Tamna). We selected one of the brighter Active Galactic Nuclei, 3C279, in order to test the feasibility of MFPR over the wide range of radio frequencies (22 − 129 GHz).

The four frequencies (22/43/86/129 GHz) were observed in left-circular mode and each of which was allocated 4 intermediate frequencies (IF) with 16 MHz bandwidth. Thus, the total bandwidth recorded was 256 MHz (16 MHz$\times$16 IFs). The digitized data in 2-bit quantization were recorded onto Mark5B at a data rate of 1024 Mbps. The correlation was performed with the DiFX software correlator [7].

The 4-frequency cross power spectrum on the Ulsan-Tamna baseline is shown in Fig. 1. A 30-second integration was used for determining the phase, fringe rate and delay for 3C279. The phase scatter is quite small up to 86 GHz but becomes larger at 129 GHz.

3. Multi-Frequency Phase Referencing test

Figure 2 shows the 4-fringe phases of 3C279 with a solution interval of 30 seconds on the Ulsan-Tamna baseline. It is to be noted that no solution failed at all frequencies during the 30-

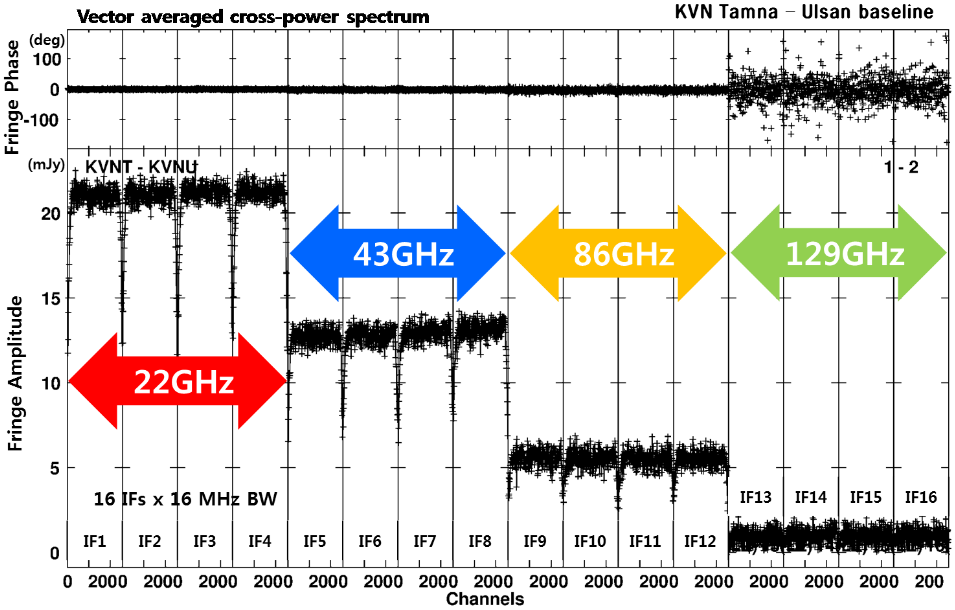

Figure 1: First simultaneous 4-frequency VLBI fringes at 22/43/86/129 GHz.

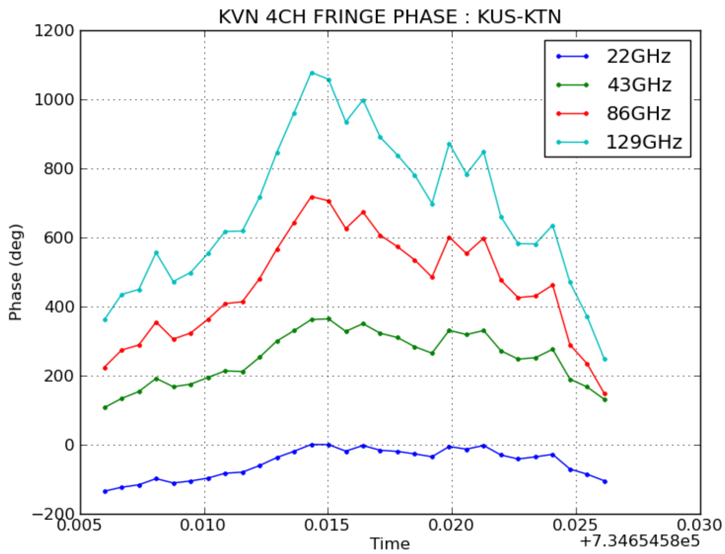

Figure 2: 4-frequency fringe phase variations for 3C279 on the KVN Ulsan-Tamna baseline.

minute observation (14:03 – 14:33 UT). The phase variations are most stable at 22 GHz and become larger with increasing frequency. We calculated correlation coefficients in order to investigate the correlation between the 4-frequency fringe phases. The correlation coefficients of the 43, 86, and 129 GHz fringe phases with respect to the 22 GHz fringe phase are 0.97, 0.91 and 0.88, respectively. High correlations of the fringe phases between the four frequencies imply favorable conditions for MFPR application up to 129 GHz.

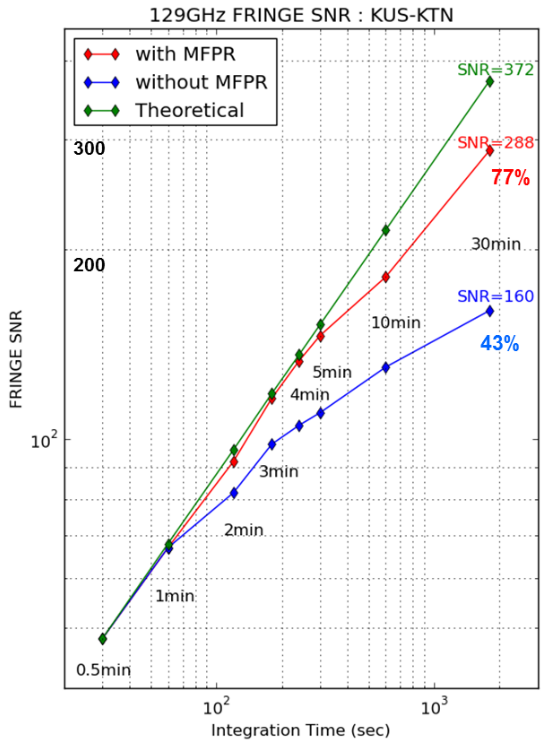

Figure 3: 129 GHz fringe SNR of 3C279 for integration times of 0.5, 1, 2, 3, 4, 5, 10, and 30 minutes. The red and blue lines represent SNR evolution with MFPR applied and without MFPR applied, respectively. The green line shows the theoretical SNR evolution.

The MFPR technique was applied to the whole data set by transferring the reference phase solutions at 22 GHz to the higher frequencies (43/86/129 GHz). For the purpose of identifying the performance of MFPR, we compared the SNR of the fringe solutions when MFPR is applied to that when MFPR is not applied, together with a theoretical estimation. The SNR of the 129 GHz fringe solutions on the Ulsan-Tamna baseline is shown in Fig. 3.

The SNR in Fig. 3 was derived from solution intervals of 0.5, 1, 2, 3, 4, 5, 10 and 30 minutes and was drawn for three different cases. The red and blue lines represent 129 GHz fringe SNR with MFPR and without MFPR, respectively. The green line shows the theoretical SNR evolution, which is proportional to the square root of the integration time. Our results are summarized as follows:

- The SNR increase is almost the same up to 1 minute whether or not MFPR is applied, implying that in practice the coherence time on the Ulsan-Tamna baseline may reach 1 minute at 129 GHz.

- The SNR when applying MFPR is remarkably consistent with the theoretical estimation up to an integration time of 5 minutes.

- At 30-minute integration, MFPR achieves a SNR that reaches 77% of the theoretical estimate and is 34% higher than the one obtained when MFPR is not applied.
- Although the SNR without applying MFPR begins to depart from that when MFPR is applied after a 1-minute integration, it interestingly still shows an increase up to our 30-minute total integration time.
- There is a marked decrease in SNR in the range 5−10 minutes when MFPR is applied (compared to that when MFPR is not applied) but after that the increase in SNR follows the trend of the theoretical value.

The noticeable decrease of SNR around 5−10 minutes when applying MFPR seems to be attributed to temperature variations in the receiver room. We are now investigating several options to minimize such periodic variations caused by the temperature control system.

4. Summary

We have tested the feasibility of MFPR over the wide range of radio frequencies from 22 to 129 GHz. Since the 4-frequency receiver system in KVN enables to observe a radio source at four different frequencies (22/43/86/129 GHz) simultaneously, the fringe phases at the four frequencies should be correlated, which was demonstrated by our test observation. Our results show that the VLBI phase at the higher frequencies can be calibrated from the lower frequency phase by using MFPR, thereby allowing us to achieve a high SNR fringe detection for 3C279 at 129 GHz by referencing to the 22 GHz fringes. This result implies that the MFPR technique can effectively compensate for atmospheric phase fluctuations, showing new perspectives for multi-frequency mm-VLBI studies. For more practical and wider applications of MFPR, we are preparing a wideband (22−129 GHz) P-cal system, in order to calibrate the phase offsets between the different frequencies and the time variations of the instrumental phase.

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