Burst Mode System toward mJy Level mm-VLBI

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Abstract. A proposal to improve sensitivity in mm-VLBI is shown based on the burst mode system. Sensitivity in mm-VLBI is largely limited by short coherence time due to atmospheric fluctuation. Thanks to recent digital technology, high speed sampler and large memory become available, which is the key of the system. The present model has a 4-Gsample/sec sampler and a 32 Gbit memory, which enables us to get wideband data of 2 GHz within a coherence time.

1. Introduction

In shorter wavelengths, VLBI observations encounter difficulties which result in low sensitivity. The difficulties are 1) small aperture of available telescopes, 2) high receiver temperature and hence high system temperature, and 3) large phase fluctuation in both receiving and local oscillator signals. In addition, a conventional IF bandwidth of 500 MHz at 1.4 GHz is another constraint to increase sensitivity.

In addition to get higher spatial resolution, observations at shorter wavelength enable us to look deep into the central part of active galactic nucleus (AGN). In fact, outbursts of AGN show the spectral peak at sub millimeter region (e.g., COURVOISIER *et al.*, 1988; MATSUO *et al.*, 1989).

Here we propose a burst mode system to increase the sensitivity in mm-VLBI observations. Recent digital technology makes it possible to develop high speed sampler that surpasses the recording speed. Together with large digital memory, Matsumoto and Kawaguchi have been making a burst mode system into reality. We describe the basic idea of the system and discuss future aspects. Detail description of the present model will be seen elsewhere in these proceedings (MATSUMOTO and KAWAGUCHI, 1994).

2. Coherence Limit

In mm-VLBI observations, coherence time is limited mainly due to the phase fluctuation in atmosphere. Furthermore, the channelization of Mk III system is another constraint: usually 2-MHz bandwidth with 28 channels. At 3 mm, for example, coherence loss was seen integration time longer than 10 seconds (BAATH *et al.*, 1992), although the situation varies with the weather condition. Assuming a loss factor of 2 for quantization, bandpass, etc., the detection threshold (SNR > 7) is 8.9 Jy for a single baseline at 2 MHz bandwidth and 10 second coherent integration with the system equivalent flux density (SEFD) of 4,000 Jy. This SEFD is almost the same as that of the Haystack telescope. This threshold is reduced by integrating 28 channels referring phase calibration signal, and by incoherent averaging of many coherently averaged segments. The threshold reduces, however, as the third to fourth root of number of segments N, instead of square root of N in coherent averaging.

Wideband sampling of 2 GHz hence reduces the threshold by factor 30 compared to 2-MHz bandwidth, and further reduces, without phase calibration, more than 5 compared to 28-channel integration without phase calibration. The phase calibration is to remove phase offset introduced by the baseband converters, hence a single channel system does not need to calibrate the offset. Instead, bandpass calibration may be needed, and it can be calibrated easily by FX type correlator.

3. Burst Mode System

As the integration time is limited by the coherence time, it is essential to expand the receiving bandwidth in order to increase the sensitivity. Providing that the recording rate is lower than the sampling rate, the idea of burst mode system comes up. Ideally, the system samples wideband signal up to the time coherence loss starts, writes it temporally in high speed memory, and then reads it out to write it onto magnetic tape. Sampling and writing phases happen alternately. Sampling time depends on the sampling rate and the capacity of the digital memory. The test model has 2-GHz sampler (4 Gsample/sec) and 32-Gbit memory which enables us to integrate 8 sec with one bit sampling, which is close to the time that the coherence loss starts at 3 mm (see MATSUMOTO and KAWAGUCHI, 1994). Unless coherence loss starts, there is no essential difference between one- and two-bit sampling. Recording time needs 128 sec for 256 Mbit/sec recording rate of K 4 recorder and the 32-Gbit memory. Under the condition of the actual recording rate, this test model will give the highest sensitivity at wavelengths shorter than 3 mm.

4. Discussion

The bandwidth of 2 GHz for the present model is still narrow at mm wavelengths or shorter, because the ratio of bandwidth to observing frequency is only 2% or less. Therefore higher frequency IF receiver system is needed to get wideband IF signal of, say, 10 GHz. High speed sampler, however, has a difficulty in sampling timing. For example, our 2-GHz sampler has a rate of 4 Gbit/s (250 ps sampling period). Then accuracy of the sampling timing should be less than 1/10 of the sampling period, or 25 ps. Parallel sampling with the 2-GHz samplers seems easier to increase bandwidth up to 10 GHz.

Recording rate is obviously the key of improving sensitivity. However, parallel recording seems applied to attain 10-GHz bandwidth recording level by the existing technology, instead of developing high speed recording. On the other hand, development of digital memory has been done very rapidly, which will support the burst mode system by replacing memory chip to high capacity one. Total capacity of the digital memory limits the integration time, and 200-Gbit memory will be appropriate, for example, at 10-GHz bandwidth and 10-sec integration. Memory chip of 256 Mbit will achieve this requirement in near future (see MATSUMOTO and KAWAGUCHI, 1994).

Short coherence time may allow us to use crystal oscillator instead of hydrogen maser because of high short term stability. More properly, a crystal oscillator locked by cesium-beam resonator can be used for high frequency VLBI observations. In fact, we have made one and have been doing test observations.

Finally, to get large aperture, phased array of mm and sub-mm arrays is very important, and hence phasing technique including real time phase correction will be subject to study. Further, the location of arrays is a matter to have good UV coverage. For site selection of building new array, we have to take into account this point.

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