

# Development of the Burst Mode VLBI

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**Abstract.** An introduction to the burst mode VLBI technology and a report on the present status of the system are presented. Three key technologies that we developed, a 4 Gps sampling LSI, a 32 Gbit large capacity memory unit and a Timing Control Unit, are described. The system check and the scientific targets are also discussed.

## 1. Introduction

A number of VLBI recording systems have been developed over the years. In the U.S.A., Mark-I (BARE *et al.*, 1967), Mark-II (CLARK, 1973), Mark-III (ROGERS *et al.*, 1983) and VLBA (NRAO, 1988) were completed. In Canada, an analog recording system (BROTEN *et al.*, 1967; MORAN, 1976) was produced. In Japan, K-1 (KAWAJIRI *et al.*, 1979), K-2 (KAWANO *et al.*, 1982), K-3 (VLBI RESEARCH AND DEVELOPMENT GROUP, RRL, 1984) and K-4 (KIUCHI *et al.*, 1991) were made.

Wide bandwidth in a new system is suitable to detect weak continuum component in radio source and to make a lot of important scientific results. Though the mm-VLBI is an important new frontier in VLBI research, the work is difficult because of low sensitivity.

The signal-to-noise ratio in the VLBI is

$$SNR = SA\sqrt{2B\tau_c} / kT_s, \quad (1)$$

where  $S$  is the flux density of the source,  $A$  is the geometric mean of telescope collecting areas,  $B$  is the bandwidth,  $T_s$  is the geometric mean of the system temperatures of the two telescopes and  $\tau_c$  is the coherence time or the longest possible integration time without significant loss of fringe amplitude due to phase noise.

The coherence time of a VLBI system is limited by atmosphere, frequency standards, and the stability and spectral purity of the electronic equipment such as the frequency multipliers (KAWAGUCHI, 1983). In millimeter wavelength, the atmospheric limitation becomes dominant and we never get away from it with ground-based network (ROGERS *et al.*, 1984). For example,  $\tau_c$  is 16 sec at 100 GHz (MORAN, 1989) which is too small to detect many sources.

Here, a large bandwidth or phase-referencing technique are effective. The

phase-referencing technique needs suitable reference around the main source. It is suitable for studying a specified source but not for the survey.

We define the burst mode VLBI as a new method of VLBI data acquisition with *wide bandwidth* exceeding recorder's bandwidth during *very short integration time* in which atmospheric and instrumental phase fluctuations are almost frozen. Purpose is to detect a lot of sources by the mm-VLBI.

## 2. The Burst Mode VLBI

### 2.1. A general view of the system

As described above, the observed bandwidth exceeds recorder's Nyquist rate. Then the system requires some buffer which we choose semiconductor memory chips. Though acquisition time to the memory is short, 4 sec (2 bit) or 8 sec (1 bit), but the time to the recorder is long, 128 sec (256 Mbps) (see Fig. 1).

Figure 2 shows the system. The IF range is 100–2048 MHz. The sampling clock is selectable, i.e.,  $4096 \text{ MHz}/2^n (n = 0, 1, \dots, 10)$  for 1- or 2-bit quantization. The burst memory has 256-bit parallel ECL 32 MHz inputs and an 8-bit parallel 32/16/8 MHz output adapted to the K-4 recorder. The system has no time label. A Timing Control Unit keeps relation between the Coordinated Universal Time (UTC) and a Track Set ID count on a K-4 tape with 32 MHz precision and will be used in correlating process.

### 2.2. Sensitivity

The comparison of the signal-to-noise ratio with non burst recording that we call "continuous recording" was investigated by MATSUTORI (1991). The continuous recording can improve signal-to-noise ratio by increasing integration time. However, the improvement has a saturation limit that is more critical at higher frequency. For the burst mode, the integration is made with very short period, around

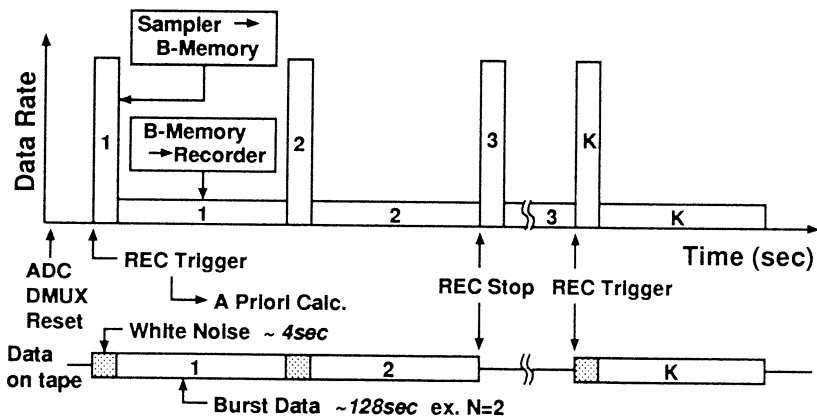


Fig. 1. Architecture of the burst mode VLBI.

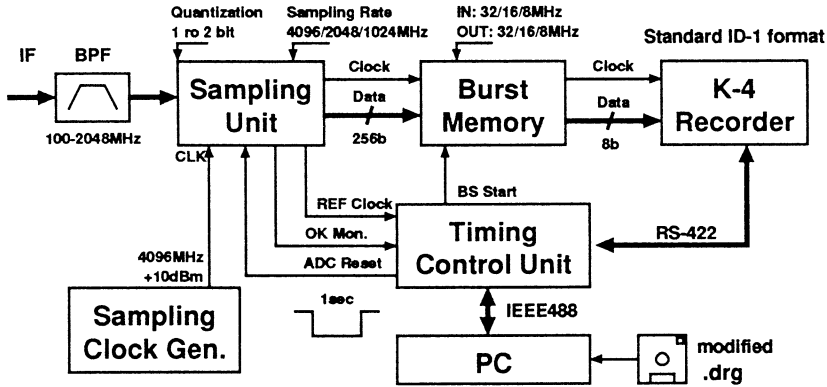


Fig. 2. System of the burst mode VLBI.

a few seconds. Consequently, the influence of the coherence loss is fairly small and the burst mode system can detect the source undetectable by the continuous recording.

Since the burst mode is a kind of time domain synthesis, possible division  $N$  saves the buffer memory. In this case, the merit of the burst mode decreases with increasing  $N$ .

The effect of the burst mode  $\eta$  is defined by next equation (MATSUMOTO, 1993)

$$\eta = \sqrt{\frac{B_{bm}}{B}} \sqrt{\frac{T_{bm}}{T}} \frac{Coh(T_{bm})}{Coh(T)}, \quad (2)$$

where  $B$  is the bandwidth,  $T$  is the coherent integration time and  $0 \leq Coh \leq 1$  is a function of the coherence factor that depends on weather conditions expressed by the Allan variance of the atmosphere. The suffix  $_{bm}$  indicates the burst mode.

The effect depends on the capacity of a memory chip. Feasible capacity at present is 16 Mbits/chip. We used 2000 chips and achieved total capacity of 32 Gbits/unit. With this memory unit, we have gain of 3.4 at 100 GHz and 4.8 at 230 GHz. Theoretical maximum improvement factor is 5.66 (Table 1).

### 2.3. Features

We summarize features of the new system.

Improvements of sensitivity for continuum

For high-frequency VLBI observations

Weak sources as reference

For VLBI reference frame works

Smaller antennas

For mobile VLBI systems for geodesy

Table 1. The effect of the burst mode and the capacity of a memory chip.

Memory chip (Mbit)	Total capacity (Gbit)	Burst time (sec)	Continuous time (sec)	Burst effect (Typ)			
				22 GHz	43 GHz	100 GHz	230 GHz
4	8	1	32	1.08	1.26	1.81	2.84
16	32	4	128	1.54	2.18	3.42	4.77
64	128	16	512	2.88	4.04	5.21	5.66
256	512	64	2048	4.81	5.47	5.66	5.66

Advantages in bad weather

Improve quality of data

No waiting for slewing, pointing, measurement of  $T_{sys}$

Improve accuracy of baseline determination

Single channel

Easy post processing hard- & soft-ware

Simple arrangement of instruments

(No need for P-Cal. The only one-set of PLO & VC is needed.)

### 3. Key Technologies

Analogue high-speed VLSI technology, high-density memory chips, their assembling technology and fully digital controlled recorder with helical scan head make possible to build up our system.

The VLSI technology named Si-based super self-aligned transistor (SST) process produced high speed (4 Gbps, 2 bit) sampling LSI. The 2-bit quantization is enough for VLBI or interferometer because of saturation in correlator's loss (COOPER, 1970). The LSI can change sampling frequency but internal sampling clock is fixed to avoid unknown oscillations in the package. Dual 2-Gbps samplers are used in a package, used alternately and they provide total capacity of 4 Gbps. Another LSI as clock generator is made, too.

The density of a memory chip has been growing according to a rule of four times larger in three years. We could use 16 Mbit-chips by the grace of the NEC company who contributed a lot of partially completed memory chips rejected in a manufacturing process. For the VLBI observation, we can approve some error in data since there is a large amount of data which is 99.9% of noise. The error is measurable and could be looked upon the known coherence loss.

The SONY company made fully digital controlled high-density (770 Gbits) recorder DIR-1000 series which have been taken into the K-4 system. The helical scanning head allows us quick synchronization and low loss of data. In order to synchronize the recording or reproduction of data, the SYNC signal available at the back connectors is used. Each rising and falling edge of the SYNC signal is considered to be one Track Set ID count. Each ID count is equal to 144,432 clock cycles (data bytes).

#### 4. System Check

We should confirm the function of the system and measure the characteristics of the aperture jitter that will cause coherence loss. A laboratory experiment of auto-correlation and cross-correlation is going on at present. Also an observational test using 45-m telescope (NRO) and 6-m telescope (Kagoshima University) with 2 GHz IF bandwidth is under consideration. In the auto-correlation test, we produce a digital pseudo-signal and check reconstructed spectrum. The amplitude characteristics in bandwidth and spurious will be evaluated. For the cross-correlation, we measure the phase stability which is very important in the VLBI by comparison of the outputs between two systems or one system and reference clock.

#### 5. Toward Scientific Observations

The scientific target depends on the system, i.e., one-baseline or multi-baseline system. At present, we are making one-baseline system for the first step. In this system, we try to detect weak sources at short wavelength.

Since the burst mode has wide bandwidth, a target which has sensitivity difficulty is suitable. For example, there is a measurement of the polarization of the galactic center, the radio galaxy and the quasars. The author has a plan of VLBI observations of the galactic center Sgr A\* with polarimeter.

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