Observation Plan of High-stable Pulsars in CRL

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ABSTRACT

We implemented a new parabolic antenna for VLBI experiments in Kashima Space Communication Center, CRL. The receivers for 330M, 610M, 1.5G, 2.2G, 5G, 8.3G, 10G, 15G, 22G, and 43GHz (with a receiver for 49GHz also under preparation) enable us to carry out not only VLBI but also various other tasks.

CRL is now making a system for observing milli-second pulsars such as PSR1937+21, which are well-known for their extreme stability. We plan to obtain very precise timings of pulses by compensating the dispersion in frequency domain with high-speed and wideband sampling. We also plan to survey other highly stable pulsars using the VLBI backend.

This report outlines the status quo of pulsar observation in CRL, and VLBI of pulsars.

Introduction

As our laboratory is responsible for time keeping in Japan, we intend to observe the milli-second pulsars for precise time keeping. We also have potential in radio astronomy and earth rotation measurement through VLBI experiments.

The characteristics of Pulsars

Pulsars radiate pulses with very stable timing, with so-called milli second pulsars such as PSR1937+21 having especially stable periods and period derivatives. Table 1 shows the profile of the PSR1937+21[1]. Since dispersion broadens the pulse width, observation using a higher frequency is preferable. But pulsars usually have a spectral index of -1 thru -2. For example the compact flux density measured in Westerbork is 0.13Jy for 609MHz and 0.017Jy for 1415MHz[2]. Therefore, less dispersion with higher frequency means fainter flux, and stronger flux with lower frequency means larger dispersion.

Fig.1 shows the Allan variance of various frequency standards, and the timing of PSR1937+21 observed in the Arecibo Observatory[3]. The slope of PSR1937+21 gives the precision of the timing observation, which is around 1

micro second. The long-term stability of PSR1937+21 reached 10^{-13}, based on the data until 1984. With the improvement of the backend and the adoption of a GPS receiver for time transfer, precision in timing measurement is now around 300 ns, and long-term stability reaches 10^{-14}. (4) As we assume that this pulsar is much more stable than any other artificial frequency standard, we anticipate the adoption of milli-second pulsars as a new time standard.

Present research activity in CRL

A new 34mø antenna has been constructed in Kashima, the specifications of which are shown in Table 2. It receives frequencies between 300 MHz and 43 GHz, although there is no receiver for 49 GHz yet. The feeds and receivers are switchable by remote control. The receivers for 300 and 600 MHz are at room temperature, with all others cooled with gas helium.

We have just started observing a strong pulsar by taking a hundred samples with low frequencies between 300 MHz and 2 GHz . Although we could detect PSR0329+54 with 300 MHz and 1.5 GHz, observation was not possible with 600 MHz because of strong and dense interferences.

Fig.2 shows the waveform of PSR0329+54 observed with 1.4GHz. The bandwidth was 2MHz. 139 periods were averaged using a digital oscilloscope.

System to be made by CRL

We are now making a one channel system for pulsar observation as shown in Fig.3. The signal is received by the 34mø antenna and converted to the video band with a K-3 video converter, which has filters from 125 kHz to 4MHz. This video signal is sampled with an 8-bit A/D converter. After conversion to digital, the signal is averaged by triggers coming from the programmed signal generator. It is then stored on a hard disc or laser disc. The whole system is controlled with an NEC PC9801 personal computer. This system will be expanded to handle up to 16 channels. Our clock system, consisting of one Cesium and two hydrogen masers, is linked with UTC(CRL) by GPS.

VLBI of pulsars

We intend to conduct VLBI experiments of pulsars to determine their precise positions and the proper motions. With the new 34mø antenna, we can make VLBI experiments from 300 MHz to high frequency.

A problem that the expected fringe amplitude is very small even for the strongest pulsars exists. There are two reasons for this. One is that particularly at higher frequencies pulsars are not very strong. Another reason is that the pulse width occupies say only about 1% out of the whole period. In this case a correlation processor must close its gate and accumulator when no pulse comes.

Our K-3 correlation processor for VLBI has this function. The correlator opens the gate from a certain point during certain bits according to the parameters which are sent from a computer every 2 or 3 seconds.

The pulsar PSR0329+54 was included in the VLBI experiment conducted this November between Kashima 34mø, Kashima 26mø, and Nobeyama 6mø. The observing frequency was 2.3 GHz and the bandwidth was 2 MHz. The fringe amplitude for the baseline between Kashima 26mø and 34mø can be estimated with Equation (1).

$$\rho = \frac{\pi}{8} \frac{D_1 D_2 S}{k} \sqrt{\frac{\eta_1 \eta_2}{T_1 T_2}}$$
Eq.(1)

In the case where the "pulsar gate" is not used, the equivalent flux density is one percent of the peak value. As the peak value of PSR1937+21 is 1Jy, the effective flux turns out to be only 10mJy. Considering other parameters shown in Fig.4, we can get a fringe amplitude of only 1.88×10^{-5}. This means that it is not possible to distinguish this fringe from noise even with 800 second integration, which is the total length of the standard VLBI tape. Therefore, we are now attempting to detect a fringe by making use of the "pulsar gate".

Summary

We have recently started observing pulsars for precise time keeping. The first step was detection of the strong pulsar PSR0329+54.

A problem with compensation for dispersion has been encountered, and one possible solution is increasing the number of channels. The output of each channel has different timing, therefore we must accumulate the data after time-shifting according to each dispersion.

Furthermore VLBI of pulsars is also an attractive method to determine the position and proper motion of pulsars.

References

(1) Rawley,L.A. et al. "Millisecond pulsar PSR1937+21: A high stable clock" Science Vol.238 '87 Nov.
(2) Backer,D.C. et al. "A milli-second pulsar" Nature Vol.300, '82 Dec.
(3) Davis,M.M. et al. "High-precision timing observations of the milli-second pulsar PSR1937+21" Nature Vol.315 '85
(4) Allan,D. et al. "In search of best clock" IEEE-IM '89 Apr.

Table 1 Profile of PSR1937+21

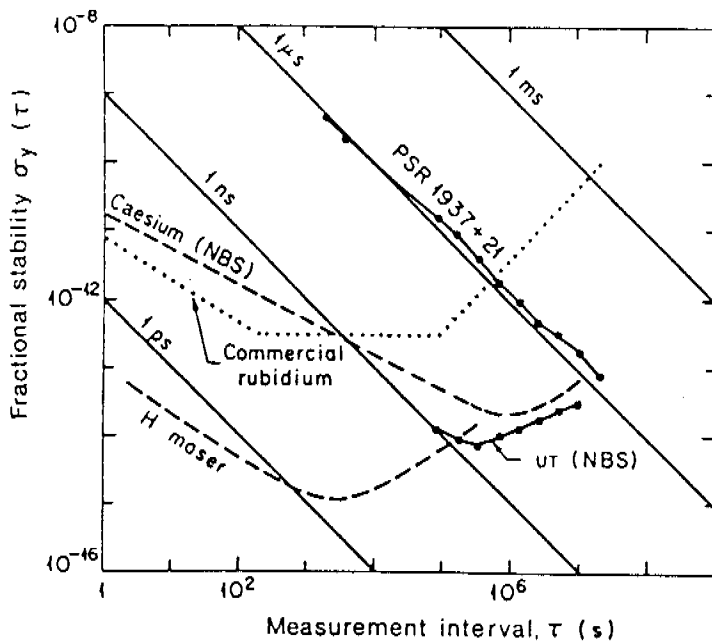|	
Period (msec)	1.55780644887275 ± 3
Period derivative (10^{-20} sec sec^{-1})	10.51054 ± 0.00008
Right ascension (1950.0)	$19^h37^m28^s.74601 \pm 0.00002$
Declination (1950.0)	21°28'01".4588 ± 0.0003
Epoch (Julian ephemeris date)	2445303.2940
Proper motion in right ascension (year^{-1})	−0".0003 ± 0".0002
Proper motion in declination (year^{-1})	−0".0005 ± 0".0003
Dispersion constant (10^{16} sec^{-1})	29.479 ± 0.001

Fig.1 Allan variance of various frequency standards and the timing of PSR1937+21 (observed in Arecibo)

Table 2 Performance of the new 34-m antenna

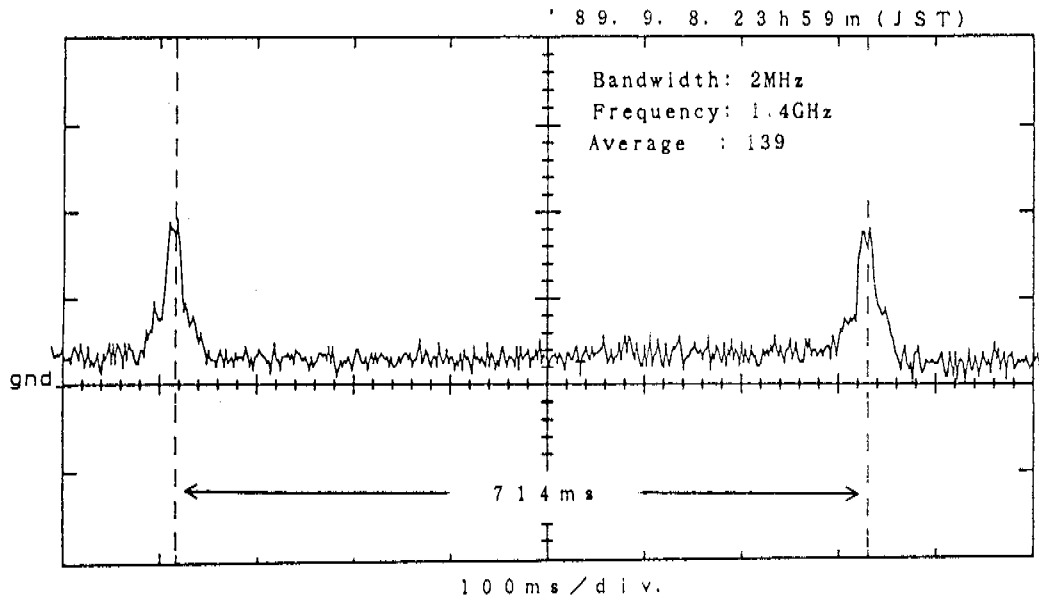| Receivers	RF band		T_{LNA} (K)	T_{SYS} (K)	G／T (dB/K)
300MHz	312 –	342MHz	43	199	15
600MHz	580 –	640MHz	(Data Not Available)		
1.5GHz	1.35 –	1.75GHz	10	38	37
2GHz	2.15 –	2.35GHz	11	71	38
5GHz	4.60 –	5.10GHz	25	60	45
8GHz	7.86 –	8.60GHz	12	53	50
10GHz	10.2 –	10.7GHz	44	71	51
15GHz	14.4 –	15.4GHz	42	106	51
22GHz	21.98 –	22.48GHz	101	189	52
22GHz	23.58 –	24.08GHz	158	223	52
43GHz	42.8 –	43.3GHz	400	1200	

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Bandwidth: 2MHz
Frequency: 1.4GHz
Average : 139

714ms

100ms/div.

Fig.2 Waveform of PSR0329+54 observed by the Kashima 34mφ antenna
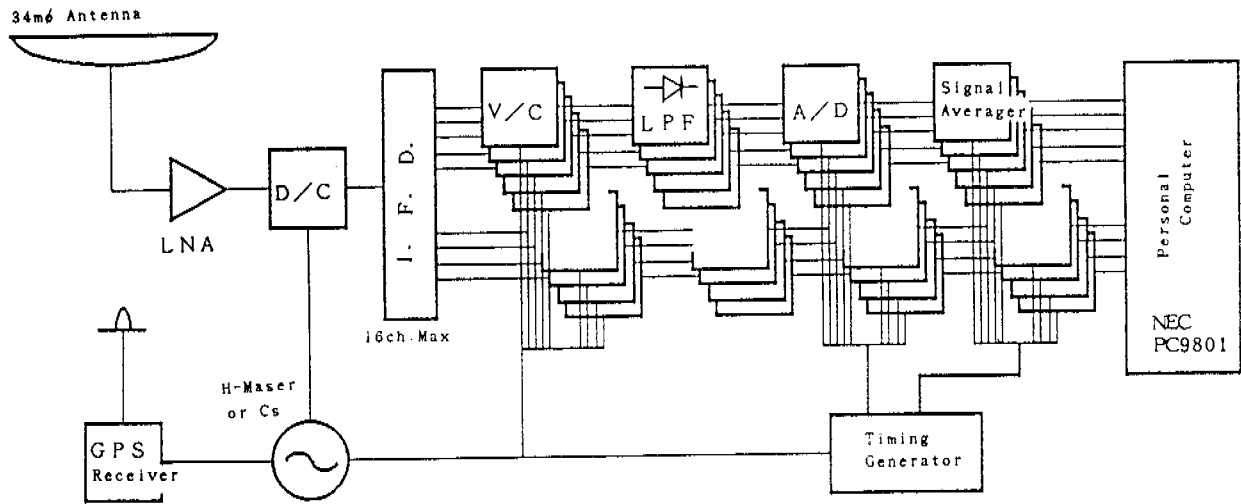
Fig.3 Pulsar observing system of CRL Kashima

ρ : Fringe Amplitude
D : Diameter
S : Flux Density
k : Boltzman constant
η : Antenna Efficiency
T : System Temp.

$D_1 = 34$ [m]
$D_2 = 26$ [m]
$S = 0.01$[Jy]*
$\eta_1 = 0.68$
$\eta_2 = 0.52$
$T_1 = 70$ [K]
$T_2 = 90$ [K]

Suffix --- 1=34mφ, 2=26mφ

* ($Jy = 10^{-26}$ W/Hz/m^2)

Fig.4 Parameters for estimation of fringe amplitude of PSR0329+54
(between Kashima 34mφ & 26mφ)