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Pulsar timing at Kalyazin (Russia)

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Abstract. Regular timing observations of millisecond and binary pulsars are made with the 64-m radio telescope at Kalyazin (Russia). Filterbank 160-channel receiver is used for observations at 0.6 GHz in two circular orthogonal polarization. Precise local time service (based upon a rubidium standards and hydrogen maser) is used for measurements of Times-of-Arrival (TOA) from radio pulsars. A local time scale is compared by GPS and TV-systems with the basic AT-scales (UTC(USNO) and UTC(SU)) within an accuracy about 50 *ns* per day. Recently the second 1.4 GHz receiver (250 kHz $\times$ 64 channels) was constructed and installed at Kalyazin radio telescope. There is a possibility to combine a part of the 1.4 GHz back-end with the 2.2 GHz front-end to produce timing observations at three frequencies simultaneously. We present a results of precise timing observations conducted by the Kalyazin pulsar system. Most of data were obtained at 0.6 GHz in 1997–1999. The data will be used for valuable applications in fundamental metrology, interstellar medium, general relativity and pulsar physics itself.

Two full steerable 64-m dish antennas are available for the pulsar observations from 1992 in a frame of the Pulsar Time Scale Program. Both 64-m antennas are the properties of the Special Research Bureau (SRB) of the Moscow Power Engineering Institute (MPEI) and are located at Bear Lakes (20 km from Moscow to the North-East) and at Kalyazin (200 km from Moscow to the North, in Tver's region). Several of the famous scientist through the world have submitted their support letters to the Russian Ministry of Sciences to involve these antennas from the Russian Deep Space Network in pulsar investigations. Drs. R.H. Frater, R.N. Manchester (Australia), Prof. B. Guinot; Kovalevskii, C. Thomas (France); Prof. Westerhout (USA) were among them. A program of upgrading the radio telescopes TNA-1500 of SRB MPEI and installation of the pulsar equipment was supported by the Ministry of Science and Technology, the Russian Academy of Science and the Education Ministry. The 64-m antennas (TNA-1500) are constructed as quasi-parabolic reflectors with homological back-structure and the Gregorian (Bear Lakes) and the Cassegrain (Kalyazin) feed

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system [1]. In many detail both radio telescopes are similar. Their parameters are shown in Table 1.

Table 1. *64-m radio telescopes (TNA-1500) of the Special Research Bureau of the Moscow Power Engineering Institute*

Main reflector (quasi-parabolic), diameter (D)	64 m
Focal to diameter ratio (F/D)	0.35.
Total surface RMS (σ)	1.1 (0.7) mm
The shortest wavelength (λ_{min})	2.0 (1.35) cm
Second mirror (d)	6 m
Pointing accuracy	5 arcsec
Fast velocity	1.5 deg/s
Angles : Azimuth	± 270 deg
Elevation	2 - 87 deg
Antenna efficiency	0.5 - 0.6
Antenna noise temperature (zenith)	15 - 20 K
Feed system:	
Broad band "unphased" horn - length	5 m
Aperture diameter	2 m
Polarization:	RHCP and LHCP
Simultaneous frequencies set:	0.6; 1.4; 2.3, 8.3 GHz
or:	(0.33); 1.7; 5.0; (22) GHz
Close cycle helium refrigerators for LNA's	(4 pumps)

The special original primary feed as long "unphased" horn (5 m length and 2 m in aperture) is inverted and constructed to make available simultaneously for observations the set of frequency bands: 0.6; 1.4; 2.2; 8.3 GHz (Pulsar and VLBI programs) or 0.39; 1.8; 5.0 (22) GHz (VLBI program, in particular "Radioastron" mission) [1]. The front-end parameters of the receiver systems are given in Table 2.

Table 2. *Parameters of the receiver systems at Kalyazin*

Receiver	PSR 0.6	PSR 1.4	VLBI 2.2	VLBI 8.3
LNA BW, GHz	0.596-0.604	1.35 - 1.45	2.075 - 2.325	7.80 - 8.70
LO frequency, MHz	562.0; 563.6	1590.0	2020.0	8080.0
Receiver Temper. K	50	25	10	12
Antenna efficiency	0.60	0.55	0.55	0.40

The helium refrigerators "close cycle system" are into operation for L, S, X - band receivers. The local computer monitoring the time service is installed by the Pushchino Radio Astronomy Observatory (PRAO) and is based on H-masers (KVARZ, Russia), Rb - standards and GPS/TV receivers. The local time is synchronised with UTC(USNO) time scale within an accuracy not worse than 50 ns. An automatical meteorological station and the Total Electron Contant (TEC)-meter making the computer monitoring of atmosphere and ionosphere parameters respectively. The radio telescope TNA-1500 at Kalyazin is stationary equipped with the PRAO VLBI S2 recorder (Canadian production) and with VLBI K4 data acquisition system temporary imported by the Communications Research Laboratory of Japan for the joint VLBI pulsar observations. For the pulsar timing program the multi - channel filter bank system was constructed by

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the PRAO and the Radio Physical Institute in Nizhnii Novgorod (NIRPhI) [2] for attachment to 0.6 GHz receiver. There are 160 channels each with 40 kHz frequency bandwidth connected as two blocks for the right- end left- circular polarisation input for 0.6 GHz frequency. A fast data acquisition system is based on CAMAC, having the minimal time resolution 10 *mcs* per channel. There is also 64 channel filter bank analyser (250 kHz frequency band per channel) for L-band receiver at 1.4 GHz. A fast data acquisition system is based on Texas Industrial computer which is capable to data collecting with sampling rate 3 *mcs* per channel.

Routine pulsar timing observation of millisecond and binary pulsars have been started at Kalyazin radio telescope in 1997 at frequency 0.6 GHz. Normally, the timing data are obtained in 2-3 day sessions every month for all pulsars. A sample of integrated pulse profiles of observed pulsars are shown on Fig.1.

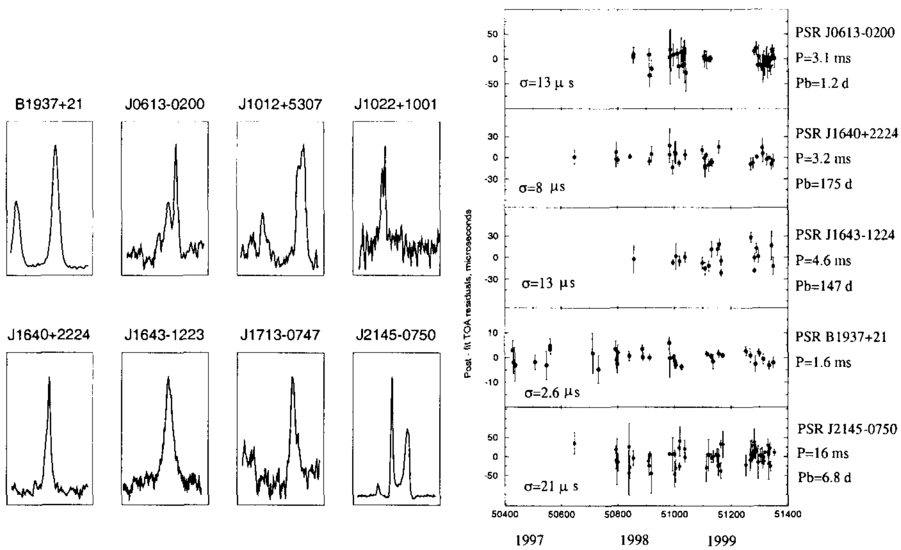

Figure 1. Pulse profiles of millisecond and binary pulsars at 0.6 MHz, observed with 64-m antenna at Kalyazin (*left panel*) and the TOA residuals after fit of pulsar spin, astrometric, and Keplerian parameters (*right panel*).

The signal/noise ratios for the observed PSR are comparable with those which are obtained with largest radio telescopes in the world. To date, we have collected Times-of-Arrival (TOAs) for eight millisecond pulsars over approximately 2-*yr* time interval, except the pulsar B1937+21, which have been monitored on a longer time interval. Observation of pulsar B1937+21 have been started in early 1993 at Bear Lakes radio telescope THA-1500 on 0.6 GHz (a half channels of receiver 0.6 GHz and orthogonal linear polarisation). The timing observations were continued with Kalyazin TNA-1500 antenna after equipping with the second part of the filter bank analyser and transporting there all receivers. This second part of filter bank allows to use both senses of polarization to eliminate systematic errors in the times of arrival of pulses caused by a change of position angle of linear polarisation of B1937+21. Over the whole period of timing (1993 - 1999) the RMS of TOA residuals are less than 3 *mcs*.

All the obtained timing data were analysed using the fit of the pulsar astrometric, spin and Keplerian parameters to the usual slow-down model of pulsar rotation [7]. These data have allowed us to obtain a parameters for the observed pulsars with high precision, which is compatible with already published data. The post-fit TOA residuals for five pulsars are shown in Fig.1. Further observations will help to obtain an improved values of the spin, Keplerian and post-Keplerian parameters for these pulsars. The timing data will also be used for a numerical applications of pulsar timing in General Relativity, Cosmology, physics of pulsars and interstellar medium. The simultaneous usage of the new 1.4 GHz receiver together with the 0.6 GHz receiver will help to take into account a variations in a value of dispersion measure and to improve the precision of timing of millisecond period and binary pulsars by reducing the scintillation effects.

Table 3. *RMS of TOA residuals of millisecond/binary pulsars from timing observations at 64-m Kalyazin antenna*

PSR	Published (1.4-1.7 GHz)		Kalyazin (0.6 GHz)	
	RMS (μs)	Ref.	RMS (μs)	Time span (yr)
J0613-0200	3.2	[3]	13	1.5
J1640+2224	8.6	[4]	8	2.0
J1643-1224	5.5	[3]	13	1.5
J1713+0747	0.4	[6]	12	0.5
B1937+21	1.2	[5]	2.6	3.0
J2145-0750	1.4	[3]	21	2.0

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