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The OH Maser Line Receiving System for the Urumqi 25m Radio Telescope *

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Abstract A maser spectral line system is newly implemented on the Urumqi 25m Radio Telescope. The system consists mainly of a cooling receiver and a 4096 channels digital correlation spectrometer. The frequency resolution of the spectrometer at the maximum signal bandwidth of 80 MHz is 19.5 kHz. After careful calibrations observation at the 1665 MHz OH maser emission was made towards a number of sources, including W49N and W75N. The observed results demonstrate that the digital correlation spectrometer is suitable for astronomical spectral line observations.

Key words: instrumentation: spectrometer — OH maser

1 INTRODUCTION

Maser sources are very strange cosmic objects. They have many interesting characteristics, such as very small maser spot sizes ($10^{13}-10^{16}$ cm), very high brightness temperatures (10^9-10^{15} K), strong polarization, and very narrow line widths (indicating a thermal temperature of a few to ~ 10 K). The line width, line center velocity and line intensity of the maser emission usually show strong variation on time scales ranging from a few days to several months. All these make masers very suitable for probing the physical conditions, dynamical structure and magnetic field configuration of star-forming regions (Moran et al. 1996; Elitzur 1992; Garay & Lizano 1999).

The 25 m Radio Telescope of Urumqi Observatory was built in 1992. As an element of Chinese Very Long Baseline Interferometry (VLBI) network, it has been outfitted with receivers

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for six wavelength bands centered near $\lambda = 92, 18, 13, 6, 3.6$ and 1.3 cm. These bands cover the spectral line emission of molecules such as OH, H_2O, NH_3, CHH_3 and OH, etc. It is therefore natural for us to consider installing a spectral line system and bringing the telescope into full play as a single dish instrument. In fact, we have built a water maser observing system based on a surface acoustic wave, chirp transform spectrometer (SAW CTS) in 1998 (Zheng et al. 1999). However, the sensitivity and the spectral resolution of the SAW spectrometer are not sufficiently high, and some of auxiliary devices have since worn out. Thus we made efforts to build a new spectral line system with a higher sensitivity and spectral resolution.

With all the improvements made on the 25 m telescope during the past few years, together with a newly installed 18 cm cooling receiver and a 4096 channel digital auto-correlation spectrometer, we finally rebuilt the spectral line system.

We outline the new spectral line system in Section 2. Results of trial observation of OH maser and preliminary analysis are presented in Section 3.

2 RECEIVER AND DIGITAL CORRELATION SPECTROMETER

Figure 1 shows a block diagram and the signal path for the new spectral line system. It includes a receiver, frequency transform devices, a digital correlation spectrometer, an antenna control computer and an operating computer. Our trial observation was made at 1665 MHz, the frequency of the OH maser emission. In the following we give some details of the new 18 cm cooling receiver and digital correlation spectrometer.

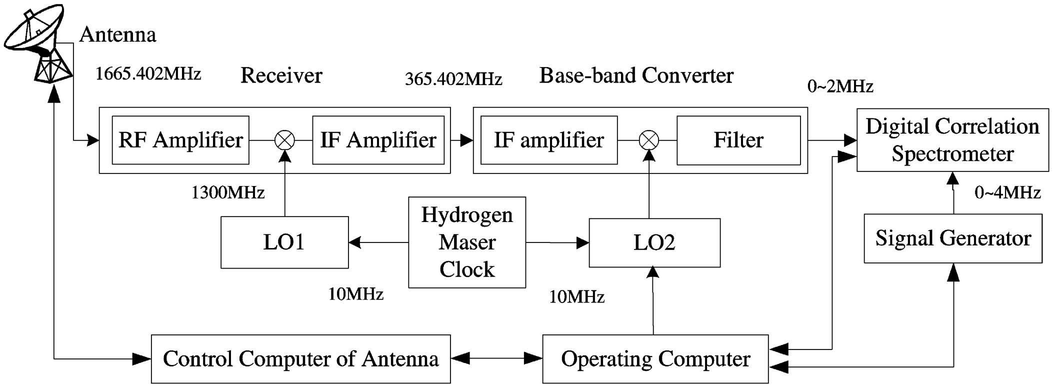

Fig. 1 Block diagram of the new 18 cm spectral line system.

2.1 Receiver

The new 18 cm cooling receiver was designed for Pulsar timing observation and VLBI projects. We have made a slight modification and added a base-band converter (BBC) of MKIV (a model of VLBI terminal) for the spectral line system.

The receiver has a dual-channel, cooling pre-amplifiers with radio frequency (RF) ranging from 1400 MHz to 1750 MHz and a total bandwidth of 350 MHz. An Ortho-Mode Transducer (OMT) at feed was used to split the polarization. High Electron Mobility Transistors (HEMT) type pre-amplifiers and dual polarization waveguide transitions are integrated into a Dewar to minimize the added noise between the feed and the HEMT amplifier. The receiver noise temperature is less than 10 K, and the system temperature is less than 30 K. The radio frequency (RF) signals are down-converted to an intermediate frequency (IF) in the range 100–450 MHz using a local oscillator (LO1) at 1300 MHz.

Then we used a BBC of VLBI terminal in our trial observation. The IF signals were fed to the BBC. The BBC has an SSB (single-side band) mixer and several low pass filters (LPFs). It is specially designed for the VLBI observation. As a second stage mixer of the receiver, the IF signals are down-converted again to a video frequency (VF) in the range 0–2 MHz using a second local oscillator (LO2) in the range 100–500 MHz. All the local oscillators in the receiver are phase locked oscillators (PLO) with reference frequency coming from the 5MHz signal of a Hydrogen maser clock. After the second conversion, the VF signals are input to the 4096 digital correlation spectrometer.

2.2 Digital Correlation Spectrometer

The most important part of the new spectral line system is the 4096 digital auto-correlation spectrometer manufactured by SPACEBORNE INC. The main advantages of the autocorrelation spectrometer, compared with the other three types of spectrometers, the Acousto-Optical, the Autocorrelation and the Filterbank Spectrometer, are compact implementations and flexibility in bandwidth and resolution combinations combined with potentially very high stability. The spectrometer includes a digitizer, a set of 32 digital correlator chips, and a parallel port interface to a personal computer system (Fig. 2). The input of the spectrometer is alternating current (AC) noise from the IF part of the radio telescope. The input signal goes to a digitizer to be digitized and sampled, producing a series of binary packets. The digitized signal is then delayed in a series of identical delay units, and the delayed samples are multiplied with an undelayed version of the same signal, accomplishing autocorrelation. The product is read out at the clock rate and the results are accumulated in counters. The accumulated totals are read out at a more leisurely rate by a computer which carries out the longer-term accumulation. After a specific integration period, the autocorrelation function is finally Fourier transformed to the frequency domain to form the estimated power spectrum. The maximum analog bandwidth of the signal inputs ranges from 1 to 80 MHz. The frequency of the clock signal is a square wave which ranges from 2 to 160 MHz from a generator. The integration time of the spectrometer can be adjusted from 209 ms to 29.98 s. The frequency resolution of the spectrometer at the maximum signal bandwidth of 80 MHz is 19.5 kHz and the frequency resolution can be changed by selecting the clock frequency.

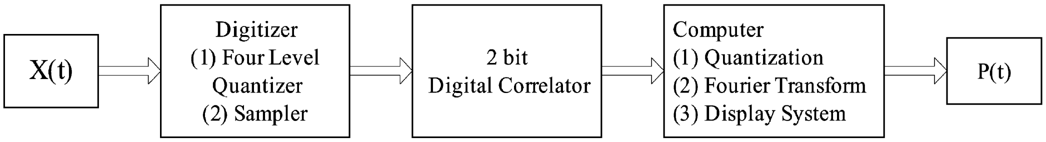

Fig. 2 Block diagram of a digital correlation spectrometer.

The digitizer is a special type of analog-to-digital converter, in which the input noise signals are quantized and sampled. It resembles the conventional analog-to-digital converters in that both perform quantization and sampling, and their difference is only in the way the decision levels and weights are assigned to the quantizers. The digitizer samples the input signal in 2-bit digital numbers at the Nyquist frequency of twice the bandwidth, i.e., Fs=2BW. The input signal times (t) of the digitizer must be a Gaussian random signal, and must have a band-limited power spectrum, i.e., $P(f) = 0$ for $f >$BW.

The digital correlator chip is S500C128A, which is a special aim Complementary Metal-Oxide-Semiconductor Transistor (CMOS) integrated circuits, with a 2×2 array of correlator units. Each unit consists of four shift registers, with two for the prompt input signal (PIN), and another two for the delayed input signal (DIN). It can operate at a clock frequency of 160 MHz with a bandwidth of 80 MHz. The longest integration time is determined by a 32-bit counter. The S500C128A chip calculates an estimate of the correlation function between a set of digitized data inputs X and another set of digitized data inputs Y (Operation Manual see *http//cfa-www.harvard.edu/∼lincoln/swis/sao1k/html/manual.sao1k.pdf*). The read-out correlation function from the correlator is fed into a computer by an enhanced parallel port (EPP) line printer terminal (LPT), LPT1 or LPT2.

2.3 Computers and Data Reduction System

The operating computer is a personal computer. It not only calculates and displays the molecule line spectrum but also implements several other tasks such as, running the observing program, sending information of the target source to the control computer, commanding the controlling computer of the antenna, setting up the frequencies of LO2 and the signal generator, and recording data from the spectrometer(see Fig. 1). The frequency and velocity in local standard of rest (VLSR) of the observed spectrum is recorded in Flexible Image Transport System (FITS) format, and processed with the GILDAS software package in the operating computer.

3 OBSERVATION RESULTS AND PRIMARY ANALYSIS

Our trial observation of OH masers was carried out from 2004 April 28 to 7 May using the 25 m Radio Telescope. The half-power beam width (HPBW) was $30'$ at 18 cm and the main beam efficiency measured was about 52%. The channel spacing was 0.487 kHz, corresponding to a velocity resolution of 0.0878 km s^{-1}. The pointing accuracy was about $15''$. The observation was made in position-switching mode. Stable noise tubes at 3.7 K and 8.8 K were used as second calibrators for right and left hand circular polarizations respectively. The atmospheric attenuation at zenith during the entire observation period was estimated to be about 0.01. The system temperature at zenith was measured to be ∼20 K. The absolute calibration of flux density was accurate within about ±20%.

Figures 3 and 4 show the 1665 MHz OH maser spectra of W49N and W75N, respectively. In each figure, the Left Hand Circular (LHC) polarization and the Right Hand Circular (RHC) polarization spectra taken by our observation are shown in the upper left and lower left panels, respectively. The on-source integration time is 16 s for both sources and both polarizations. Also shown in the right panels of Figures 3 and 4 are the corresponding spectra from Kent and Mutel (1982, hereafter KM82) and Baart et al. (1986, hereafter BCDNR86) for W49N and W75N, respectively. It should be noted that these two sets of spectra used for comparison were taken at different spatial and spectral resolutions. The W49N spectra from KM82 were taken by using two-station VLBI (The North Liberty Radio Observatory 18.3 m telescope and the NRAO 42.7 m telescope), with a synthesized HPBW of ∼0.0422 and a spectral resolution of 0.56 km s^{-1}, while the W75N spectra from BCDNR86 were observed with the Jodrell Bank Observatory 76 m telescope, with an HPBW of $\sim 10''$and a spectral resolution of 0.2 km s^{-1}.

For W49N, the KM82 spectra show a velocity span of 0–22 km s^{-1} for both the LHC (Fig. 3, the upper right panel) and the RHC (Fig. 3, the lower right panel) OH maser features. The strongest feature was ∼300 Jy at 21 km s^{-1} (LHC) and ∼250 Jy at 16 km s^{-1} (RHC). Our spectra indicate clearly more maser features thanks to the higher spectral resolution. The

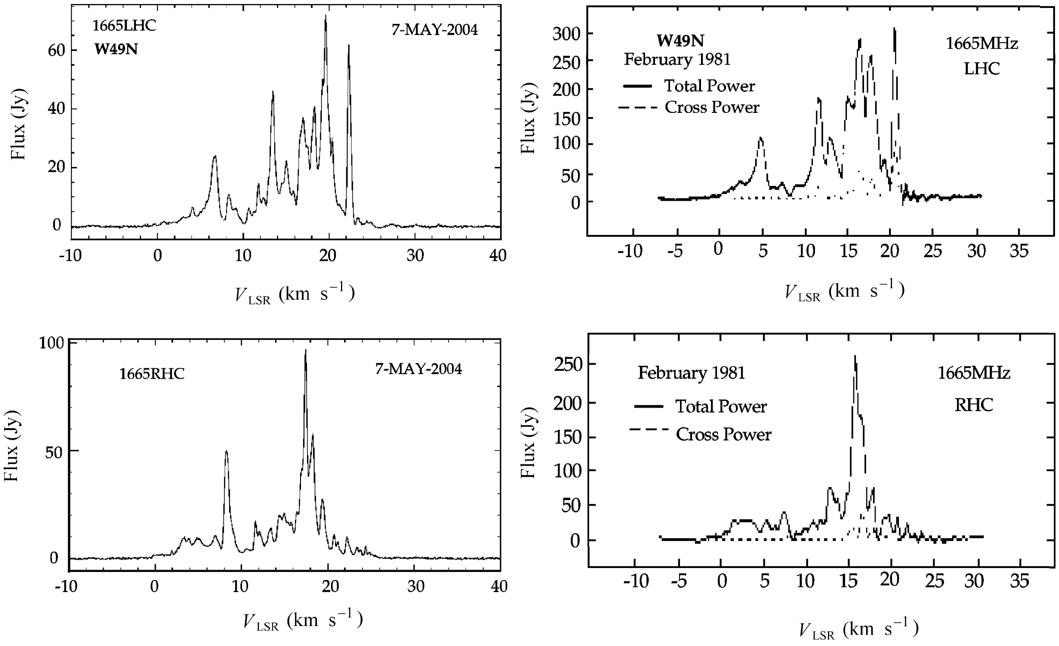

Fig. 3 The 1665 MHz OH maser spectra of W49N got by us (left) and by Kent et al. (1982) on the right.

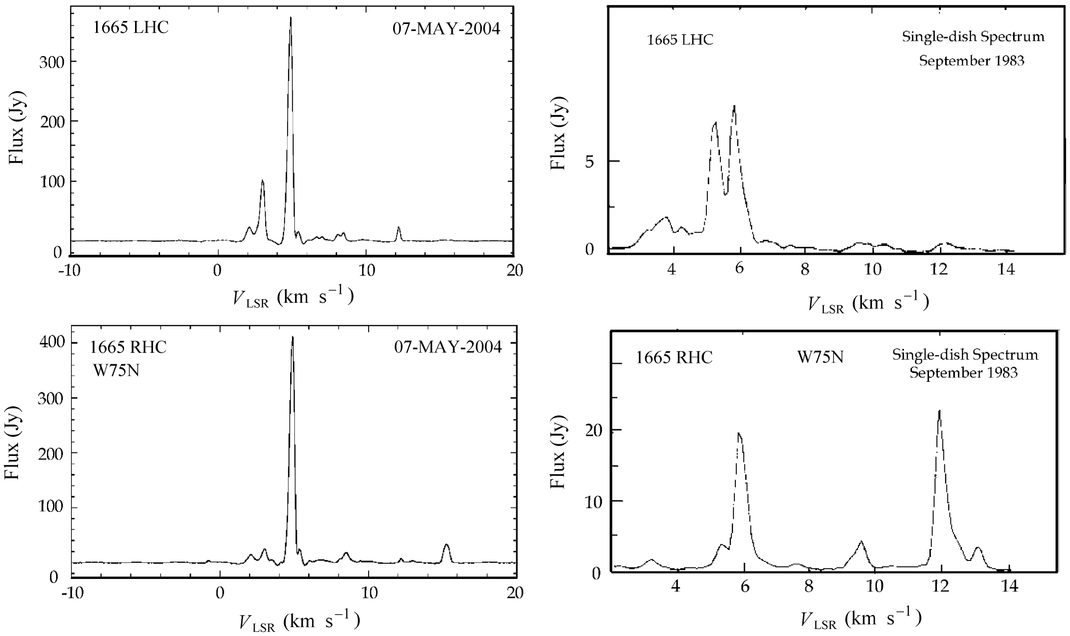

Fig. 4 Spectra of W75N of 1665 OH maser obtained by us (left) and by Baart et al. (1986) on the right.

velocity spans are both 2–26 km s^{-1} for the LHC and RHC maser features. The strongest maser feature is ~72 Jy at 20 km s^{-1} (LHC) and ~102 Jy at 18 km s^{-1} (RHC). The differences are easy understood in terms of maser variations as well as the tremendous difference in spatial resolution. In general, the overall distribution of the OH maser features of our spectra is quite similar to that of KM82.

For W75N, the spectra of Baart et al. (1986) showed a velocity span of 2–7 km s^{-1} (LHC) and 2–14 km s^{-1} (RHC). The strongest LHC and RHC maser features were ~8 Jy at 5.8 km s^{-1} and ~24 Jy at 12 km s^{-1}, respectively. Our spectra have wider velocity spans of 1–13 km s^{-1} (LHC) and 1–16 km s^{-1} (RHC). The strongest maser features are both at 5 km s^{-1} with comparable intensity for the LHC (~380 Jy) and RHC emissions (~420 Jy), both of which are much stronger than those of BCDNR86. It is clear that the overall distribution and the intensity of the OH maser features of W75N have changed drastically during past 18 years, and some "bursts" in the maser features may have happened.

The comparison of our OH maser observation of W49N and W75N at 1665 MHz with those in the literature demonstrates that our digital auto-correlation spectrometer system has a very high sensitivity and spectral resolution that is ideal for maser line observations. We expect this system can be used to observe H_2O, NH_3, and CH_3OH in the near future.

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