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Upgrade Procedure for the Delingha 13.7-m Telescope

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Abstract The 13.7-m millimeter-wave radio telescope of Purple Mountain Observatory operates at 3200-m above the sea level near Delingha, Qinghai Province, China. Equipped with a superconducting SIS receiver, the telescope is used in the millimeter-wave band ranging from 85 to 115 GHz. An upgrade procedure is reported here which includes a superconducting SIS receiver, a new phase-locked local oscillator, a dedicated multi-line backend system, and a new control system based on industrial computer with PCI bus. With the dedicated multi-line backend system, the CO and isotopic lines around 110 GHz are obtained simultaneously. In recent years, scientific activities with this telescope have been focused on studies of Galactic molecular clouds and star formation regions, including surveys of molecular lines from IRAS sources and large-scale map of molecular clouds. Other programs include studies of the circumstellar envelope of late-type stars and interaction of Galactic supernova remnants with dense molecular gas.

Key words: telescopes: radio telescope — millimeter wavelength astronomy — instrument

1 INTRODUCTION

Millimeter-wave radio astronomy was developed as an important branch of observational astronomy. Most of the targets in the millimeter-wave region are weak radio sources, challenging the sensitivity, bandwidth, over-all system stability of the observing facility. To achieve a low-noise heterodyne receiver system is of primary importance, since the sensitivity is proportional to the system noise temperature and inversely proportional to the square root of the product of bandwidth and integration time. Obviously, by reducing the system noise temperature, the receiver will become more sensitive, and the necessary integration time will be significantly reduced and the observing speed is enhanced. Furthermore, the large-scale study of interstellar molecular clouds requires a system possessing multiple signal channels, long-term stability and high efficiency.

The Delingha 13.7-m radio telescope, the only large millimeter-wave telescope in China, is located near Delingha city in the west of China at an altitude of 3200 meters above sea level. It operates mainly in the band of 85–115 GHz for interstellar molecular spectroscopic observations. The telescope was built from the early 1980s to the 1990s, originally with a semiconductor Schottky receiver. Since 1998, several significant upgrades have been made, including an SIS receiver at first, a new phase-locked local oscillator, more recently a multi-line backend system, and a control system based on industrial computer with PCI bus.

This paper describes the upgrade efforts and some recent observational results derived from the upgrading.

2 90–115 GHz SIS RECEIVER SYSTEM

2.1 90–115 GHz SIS Receiver

The 90–115 GHz SIS receiver (Shi et al. 1995; Shi et al. 1997) consists of a corrugated feed horn, a 20-dB directional coupler, a tuneless waveguide SIS mixer with a parallel-connected twin junction (PCTJ, Shi et al. 1994), and a set of cooled HEMT IF preamplifier. The preamplifier set is composed of an isolator and S-band HEMT amplifier (developed by Nitsuki Ltd.). The focused signal is received by the feed horn and is combined with LO signal in the coupler. The two signals are mixed when they are fed to the SIS mixer. Then the filtered IF signal is pre-amplified by the cooled low-noise HEMT amplifier mounted on the 20 K-stage of the Dewar. The output IF signal is further amplified to an appropriate level by the main IF amplifier at room temperature and is finally fed either into the AOS backends to give a spectrum of the observed source, or into the continuous backend to measure the total power or switching power.

The temperature of the receiver noise at the front of the Teflon lens measured with the Y-factor method is typically better than 45 K (DSB). The typical temperature of system noise, including the contribution from the sky and propagation loss, measured at EL=70° on a clear autumn day (September 1, 2003), is shown in Fig. 1.

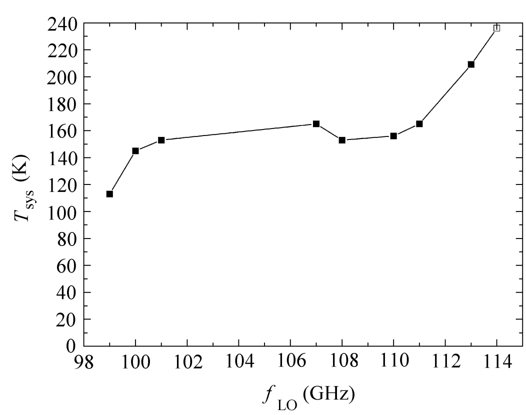

Fig. 1 Typical temperature of system noise versus local-oscillator frequency measured at EL=70° on 2003 September 1. The receiver operated in the DSB mode with an IF frequency of 2.64 GHz and an IF bandwidth of 800 MHz.

2.2 4-K Cryogenic System

A modified GM 2-stage 4-K refrigerator, manufactured by Sumitomo Heavy Industry, Ltd, Japan, was used to cool down the SIS receiver. This refrigerator consumes ∼ 5 kW and gives a cooling power of 1 W. It can be operated in any direction without appreciably reducing the cooling capacity, which is necessary for a receiver system co-moving with the antenna in the elevation direction.

The 4-K cryostat, employing 300- and 40-K shelters, provides two cooling stages of 40-K and 4-K. The SIS mixer was mounted on the 4-K cooling stage. Thermal isolation of the cryostat was carefully dealt with. The IF HEMT amplifier, which gives ~50 mW of thermal emission, is separated from the 4-K stage by a thin Teflon sheet. The temperature at the amplifier was measured to be about 30-K. An RF window passes the incoming signal and shields the vacuum state inside the cryostat. An IR filter of appropriate thickness is put behind the entry window to fully isolate the thermal radiation and it does not introduce any appreciable signal loss. Similarly, to reduce the thermal conductivity, the IF cable and LO-injection wave guide were made of Copper-Nickel alloy and deliberately lengthened.

2.3 85–115 GHz Phase-Locked Gunn Oscillator

The previous Gunn oscillator suffered from stability and noise problems over the whole range of 85–115 GHz after years of operation. We replaced it with a new phase-locked Gunn oscillator (PLO) developed by Radiometer Physics GmbH.

The PLO uses a standard feedback scheme in both frequency and phase detection. A fraction of the Gunn oscillator output is coupled to a harmonic mixer at which it is mixed with the Nth harmonic of the reference signal from a frequency synthesizer ($f_{\rm syn}$), yielding a beat component of frequency $f_{\rm IF}$. This beat signal is phase locked to a temperature-stabilized crystal oscillator of fixed frequency 100 MHz. By this process the Gunn oscillator will achieve a long-term frequency stability of 10^{-9} and a phase noise performance of –92 dBc at 100 kHz offset measured at the 100 MHz beat signal. The Gunn oscillator can be mechanically tuned from 85 to 115 GHz, and finely tuned by the bias voltage of the Gunn diode with a tuning sensitivity about 250 MHz per volt. Moreover, the frequency of the Gunn oscillator can be set to any value from 85 to 115 GHz by adjusting the input signal frequency ($f_{\rm syn}$) and choosing an appropriate harmonic number, which typically is between 19 and 25.

Variation of the diurnal ambient temperature at the telescope site is considerable ($\sim 30^\circ$C). It is well known that either the frequency or power of the Gunn oscillators will drift when the ambient temperature varies. A large frequency drift may cause unlocking of the PLL, while a power drift will make the SIS mixer deviate from its optimum pumping condition, causing a deterioration in the performance of the mixer. For this reason, a temperature-stabilization assembly was developed for the Gunn oscillator, with which the temperature of the oscillator can be stabilized to an accuracy of $\pm 0.5^\circ$C independently of the ambient temperature.

2.4 The Quasi-Optics

Since the zenith optical depth τ at the Delingha telescope site is typically lower than 0.3 at 115.3 GHz in the winter season, and the SIS mixer has excellent noise performance, the receiver adopts a DSB scheme in order to receive a number of line signals using the multi-line backend system introduced below. The quasi-optical system consists of an elliptical mirror, a plane mirror, and a Teflon lens. The mirrors are installed in an aluminium frame and the Teflon lens is fixed in front of the RF window of the 4-K dewar. Position accuracy of these quasi-optical components is guaranteed by mechanical machining.

The telescope adopts the standard "chopper-wheel" scheme (Ulich & Haas 1976) to calibrate the antenna temperature scale of the observed source with instantaneous correction of the atmospheric absorption. Fixed at the secondary focus of the antenna, the chopper wheel switches from the observation mode to the calibration mode during spectral line observations, or switches between the source and background observation modes at a chopping frequency of

15 Hz during continuous observations.

3 THE MULTI-LINE BACKEND SYSTEM

Observations of the three CO isotopic lines around 110 GHz (^{12}CO, ^{13}CO, and C^{18}O) are of fundamental interest in most observing programs. The previous system can only receive one spectral line at a time. It is obvious if these three lines can be observed simultaneously then the observing efficiency will be greatly improved. Furthermore, because the calibration for three lines will be based on the same observing procedure at the same time, errors in the spectral intensity determination due to the atmospheric fluctuation, pointing variation and the like that degrade the results when we observe these lines individually at different times can be significantly reduced and the resulting measurement of the relative intensity of the three lines will be more precise. This is of particular importance when the signals are weak. The simultaneous observation is achieved by the dedicated multi-line backend system.

Since CO and its isotopic lines at $J = 1-0$ transition are separated approximately by 5.5 GHz in frequency, one can include all the lines in one broad IF band by using double-side band mixing with the LO frequency close to the middle of the three lines. Figure 2 illustrates the receiving scheme, and Fig. 3 shows the block diagram. The center IF frequency is set to 2.64 GHz, and IF bandwidth of 800 MHz. The first three channels, AOS-I, AOS-II, and AOS-III, give respectively the C^{18}O, ^{13}CO, and ^{12}CO lines and the forth channel yields the total power of a source. Doppler tracking of the line system was made for all the three channels. The ^{12}CO line was carried out by the first-stage phase-locked local oscillator. The C^{18}O and ^{13}CO lines were further tuned out by the secondary-stage IF mixers. Sample spectra taken by the multi-line system are shown in Fig. 4.

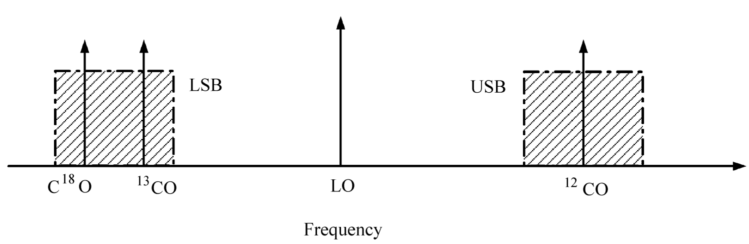

Fig. 2 Three CO lines observed simultaneously.

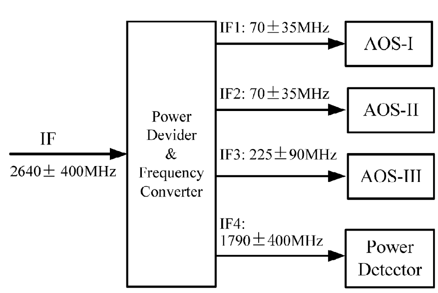

Fig. 3 Simplified block diagram of the multi-line backend system.

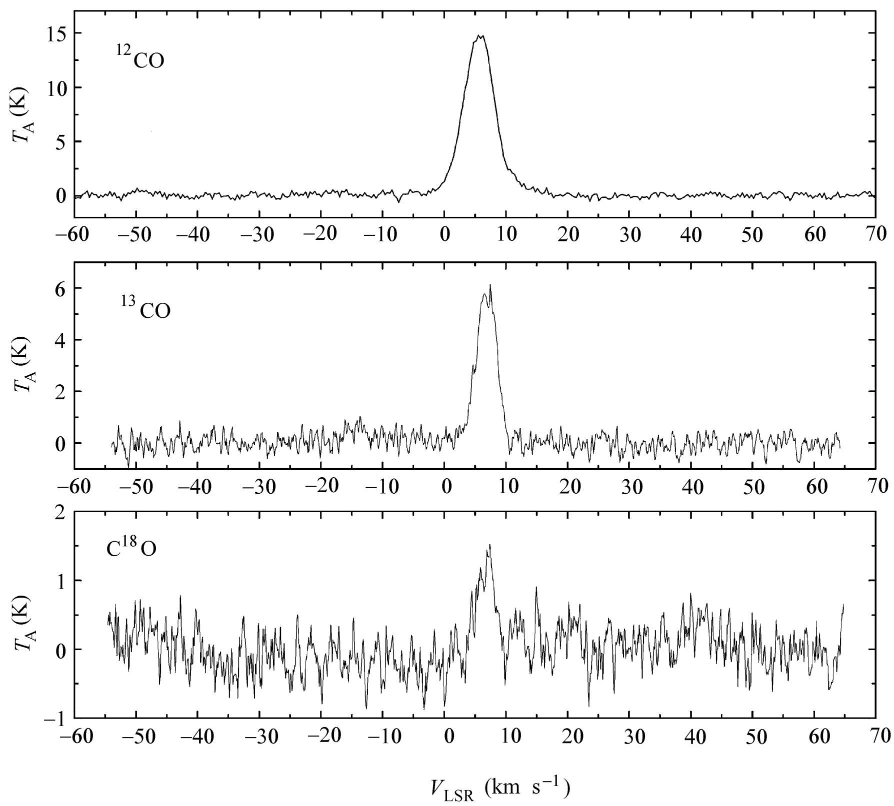

Fig. 4 Simultaneously observed raw spectra of the three CO lines. The spectra were taken of the molecular cloud NGC2264, with 1-minute on-source integration time. The base lines are fairly flat. The rms noise level is, 0.32 K for the narrowband ^{13}CO, C^{18}O lines, and 0.26 K for ^{12}CO line.

4 THE NEW TELESCOPE CONTROL SYSTEM BASED ON PCI-BUS

In addition to the above upgrades, we have also upgraded the previous PDP-11/44 based control system with an industrial computer of PCI-bus under real-time Linux OS and self-developed software coded in C. Most of the I/O hardware conform to the standard industrial interfaces, such as IEEE-488, RS-232, and RS-422. Part of the I/O operations were achieved through the multi-purpose I/O board made by the National Instruments. The positional library, SLALIB, developed by the Rutherford Appleton Laboratory (Wallace 1997), was employed for coordinate transformation as well as for calculating stellar positions, and the solar system ephemeris DE405, released by JPL, was used for the ephemeris of solar system objects. The control system manipulates the antenna movement, adjusts the receiver, and conducts data acquisition from the back-ends. The data are stored in the standard FITS format for further processing with GILDAS/CLASS and other data reduction software packages. The control system also provides a set of software tools to fulfil the purposes of system diagnostics and various testing procedures.

5 SCIENCE ACTIVITIES WITH THE 13.7-m TELESCOPE

In recent years, scientific activities with this telescope include surveys of molecular lines from IRAS sources (e.g., Jiang et al. 2000; Yang et al. 2002), investigations of interstellar molecular structures (e.g., Wu et al. 2001a; Pei et al. 2001), mapping of high-velocity molecular outflows (e.g., Wu et al. 1999; Qin & Wu 2002), searching time variability of H_2O masers (e.g., Xu et al. 2001b; Xu et al. 2000; Zhou & Zheng 2001), studies of molecular properties of star formation regions (e.g., Wu et al. 2001b; Sun & Sun 2000, Xu et al. 2001a), tests of molecular properties of HII regions (e.g., Sun et al. 2002; Xu et al. 2002), searches for evidence of interaction between dense molecular gas and supernova remnants and probing the origin of cosmic ray emission (e.g., Yang et al. 2003, in preparation).

Yang et al. (2002) conducted a large-scale CO ($J = 1 - 0$) survey of the cold IRAS sources along the northern Galactic plane. According to their studies, out of 1912 selected IRAS point sources, 1331 were detected to have significant CO emission, showing that 70% of the cold IRAS sources are associated with molecular gas. Among the detected sources, 351 have high-velocity CO wing emission, and these 351 include 289 new detections. The results of the survey suggest that 41% of the CO sources are undergoing the HVF phase.

Figure 5 shows an example of the ^{13}CO line mapping towards the star-forming region AFGL 5157. A dense molecular core, with a mass of $1.8\times10^3\ M_\odot$, was found in the region. The region has an associated NH_3 core found earlier by Torrelles et al. (1992). Within this molecular core, four H_2O masers, a high-velocity molecular outflow source, and a number of shocked jets and knots detected by narrow-band $H_2 v = 1 - 0\ S(1)$ imaging in near infrared, inhabit the central region, showing it to be an active site of cluster formation (Chen et al. 1999, 2003).

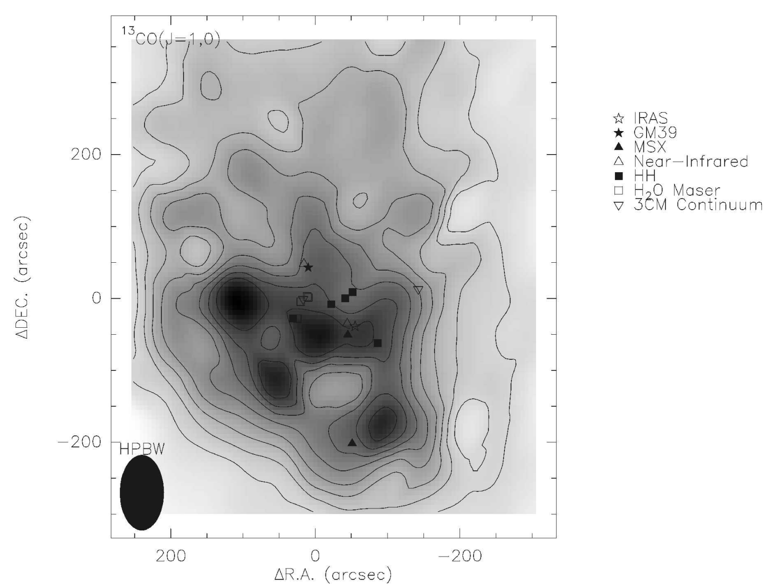

Fig. 5 Observation in the ^{13}CO line towards AFGL 5157 (Lu & Yang 2003, in preparation).

6 SUMMARY

An upgrading procedure has been accomplished for the Delingha 13.7-m Telescope. The superconducting SIS receiver is found to have a sensitivity that is approximately 10 times higher than the previous Schottky receiver. The new LO and temperature stabilization assembly has made the telescope more stable in routine operations. The multi-line backend system and new control system have improved the line observing speed by at least three times and the quality of the observed CO lines. The above efforts have enhanced the activities in the observations of interstellar molecular clouds, star-forming regions, late type stars and other topics of astrophysical interest.

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