A NEW HYDROGEN-MASER TIME AND FREQUENCY STANDARD AT SHESHAN VLBI STATION OF SHANGHAI OBSERVATORY

Z.C.Zhai, H.X.Huang, C.F.Lin, G.X.Jiang
W.H.Luo and J.F.Lu
Shanghai Observatory, Academia Sinica, Shanghai 200030

Abstract

A new kind of hydrogen-maser time and frequency Standard was installed this September at sheshan 25-meter radio telescope in Shanghai, for very long baseline interferometry (VLBI) experiments. This standard is a readily transportable, rugged and completely integrated frequency standard. The entire system is engineered as a unit, and all electronics were mechanically and electrically integrated with the physical portion into the overall design. This paper describes its design feature and structure as well as the measured results of its performance. Its applications and data in VLBI experiment are also included.

INTRODUCTION

The hydrogen maser is generally regarded as the ideal time and frequency standard for VLBI. It has a unique combination of superior short-term and long-term stability. Further, the maser is a primary standard with unsurpassed resettability of frequency.

In the past, the size, weight, and general awkwardness of the equipment have limited the use of the maser to fixed installations. The masers which have been used for several years in Sheshan VLBI station are this kind of hydrogen masers, which were made earlier by Shanghai Observatory[1-3].

A hydrogen maser described in this paper is a new kind of maser, designed to be easily transportable and rugged enough to withstand the normal rigors of being moved from one station to another. It was transported by truck from Zi-Ka-Wei section to SheShan VLBI station, for VLBI experiments. In the new design, we absorbed many design ideas of masers developed by Dr.R.F.C.Vessot at the SAO[4].

DESIGN FEATURE OF THE NEW MASER

The design philosophy for new maser developed from several basic aspects. First, the maser design emphasizes good intrinsically stability with respect to both mechanical and thermal perturbations. It is enclosed in a very carefully controlled thermal and mechanical environment to minimize maser detuning by variations in ambient conditions, and thus to permit stable maser operation over long periods of time without requiring autotuning or other adjustments.

Second, the new maser is a compact, relatively light-weight, rugged, and easily transportable standard. The entire standard was to be silf-contained in a single standard-sized rack cabinet. All electronics including the phase lock receiver were to be mechanically and electricallly integrated into the overall design. It is a relatively small instrument weighing 250kg and requiring a source of only 28 volts DC at 200 watts to operate. The third feature is that there is a circulating air system in the rack cabinet. The system, which controls the temperature of the pump, the dissociator, and the upper maser electronics, is an entirely independent system with selt-contained sensors and electronics. In addition, the new maser incorporates an extensive monitoring capability. Four front panel mounted meters, each with an eight-position selector switch are located on the monitor panel to provide quick-look monitoring of 32 fuctions. These include all main power-supply voltages, all heater voltages, hydrogen dissociator operating conditions, receiver/synthesizer signal level, and phase-lock control voltages. The monitor panel also includes a small four-digit counter and LED readout for displaying the output frequency of the synthesizer.

Fig. 1 shows the photograph of the complete maser system with the side panel removed.

NEW MASER OSCILLATOR AND CLOCK SYSTEM

The design features of the Shanghai Observatory new hydrogen maser were described in detail in earlier paper[3]. Fig.2 is a diagram of the major structure of the maser. The cavity resonator is an extremely rugged CERVIT structure. Longitudinal stresses produced by the thermal expansion coefficient of the resonator hold-down can are absorbed by a large Bellville spring washer. Thermally induced radial stress in the resonator base is relieved by a 40-glass balls quasi-kinematic mount. Barometrically induced stresses on the vacuum tank are isolated from the cavity resonator by a double-base structure. It should be noted that the design philosophy of the maser emphasizes good Long-term frequency stability without the necessity for continuous automatic tuning. The tuning procedure is usually required only when the maser is moved to a new location or before VLBI observations.

The entire maser clock system is shown in block diagram in Figure 3. A 100MHz crystal oscillator is phase locked to the maser signal to provide standard frequencies at levels useful to the clock system. A simple dual-conversion receiver is used to generate the phase locking signals; a synthesizer is also used to set the time scale. 1MHz and 5MHz signals, derived from internal dividers in the crystal oscillator, is used to drive the VLBI timing system.

THE PERFORMANCES OF NEW MASER

A comprehensive series of environmental and short-term stability tests on the new maser has been evaluated before the new maser was moved to Sheshan VLBI station. Figure 4 shows the short-term frequency stability of the new maser. It can be seen from the Fig.4, the stability data keeps 10^{-15} levels for the periods of time beyond 100 seconds.

The new maser has been working continuously for more than a year before it was moved to Sheshan VLBI station. Figure 5, as an example, shaws the comparison data measured between the new maser and the master Cs clock of AT(SO).

In the environmental tests, the output frequency was carefully monitored while one of the environmental conditions was varied. The results of each of these environmental tests is itemized below:

1. Output frequency vs temperature tests - The new maser was placed individually in the test chamber and the chamber temperature was cycled between 22^0 to 31℃, the rosultant variation in output frequency was plotted.

2. Barometric pressure tests - No output frequency variations were observed as the maser was individually subjected to barometric pressures of 25 mmHg above and below ambient pressure with a two-hour dwell at each extreme.

3. Magnetic field Sensitivity tests - It was measured by placing the maser under test within a 2.4-meter diameter set of Helmholtz coils and varying the current through the coils. A about 0.4 gauss axial field was used in the tests.

A summary of the environmental sensitivities of the new maser is presented in table 1.

Table 1. Environmental sensitivities[6]

conditions	Sensitivities		
Temperature (22℃~31℃)		slow coefficient	fast coefficient
	ΔT up	2.9×10^{-14}/℃	1.2×10^{-14}/℃
	ΔT down	3.0×10^{-14}/℃	1.3×10^{-14}/℃
Barometric pressure (±25mmHg)	$< 1\times10^{-14}$		
Magnetic Field (±0.4G)	1.1×10^{-12}/G		

APPLICATION

1. Tuning the hydrogen maser

The oscillation frequency of a hydrogen maser is "pulled" by the maser cavity resonantor. The amount of pulling is a fuction of cavity detuning and the line width of the atomic resonance:

$$\nu = \nu_H + [(\nu_c - \nu_H)/\nu_c \cdot Q - (0.29\nu\, a_0^2 h V_c)/(Q\mu_0^2 \eta V_b)]\Delta\nu_L \qquad (1)$$

If the cavity is tuned to a frequency ν_{co} such that

$$\nu_{co} = \nu_H\,[1 - (0.29\nu\, a_0^2 h V_c / Q^2 \mu_0^2 \eta V_b)]^{-1} \qquad (2)$$

then the term in brackets in equation(1) vanishes and

$$\nu = \nu_H$$

The maser oscillates at the centre of the atomic resonance line.

The cavity is tuned to ν_{co} by madulating the flux of atoms entering the storage bulb. It can be shown that the spin exchange contribution to the line width is directly proportional to the flux, and when the cavity is at the tuning point ν_{co}, then ν is independent of line width and therefore also independent of the total hydrogen flux.

The maser can be tuned by using another hydrogen maser as a reference or a frequency reference less stable than that of the maser itself. At the Sheshan VLBI station, hydrogen maser is tuned by using a microcomputer system. The end results for tuning point and line Q are displayed on the screen.

2. VLBI data

During VLBI experiments, hydrogen maser performances are monitored by a microcomputer real-time measuring system. The stability data is shown not only by Allan Variance, but also in a form that might be more useful for VLBI experimenters. Fig. 6 shows phase difference in seconds with only a frequency offset term removed from the data. Notice that the data has the quadratic behavior associated with uniform frequency drift. Fig.7 shows the same data with a uniform frequency drift term also removed.

CONCLUSION

For VLBI observations, the hydrogen maser is the suitable satisfactory frequency standard. Shanghai Observatory new hydrogen maser has demonstrated that it can be used routinely and reliably for VLBI. Doubtlessly, the features of ease transportation and convenient to operate make the maser to be also a ideal time and frequency standard for other fields.

REFERENCES

[1]. Z.C.Zhai, JIETE, 27.11, 1981;

[2]. Z.C.Zhai, etc. proc of 38th annual symposium on Frequency control, 1984;

[3]. Z.C.Zhai etc, proc of 18th PTTI meeting, 1986;

[4]. R.F.C.Vessot, M.M.Levine, E.M.Mattison etc, proc. of 8th PTTI meeting,1976;

[5]. Z.C.Zhai, H.X.Huang etc, proc, of 41st Annual symposium on Frequency control, 1987;

[6]. Z.C.Zhai, H.X.Huang etc, "Electromagnetic metrology", International Academic Publishers, 1989.

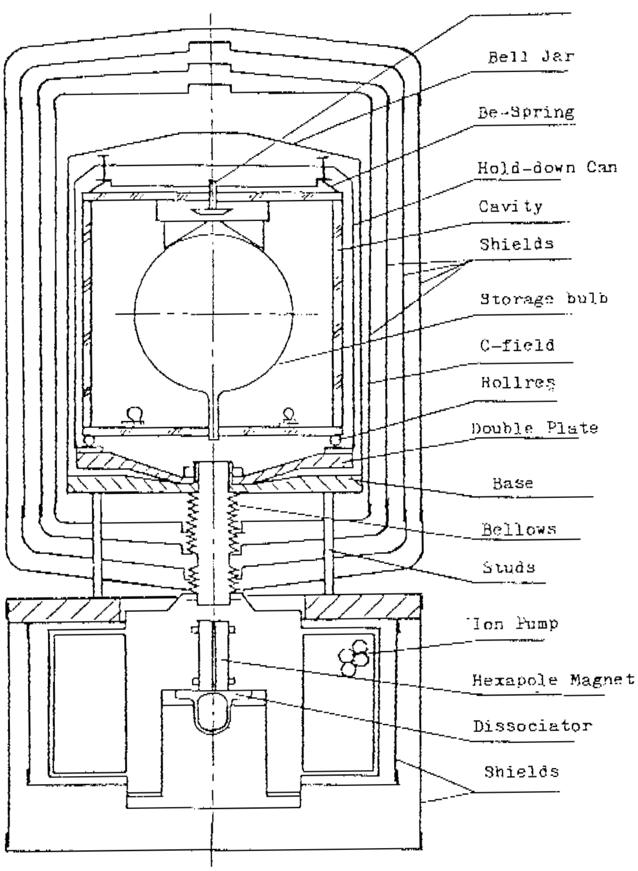

Fig 2 Major Structure of the maser oscillator

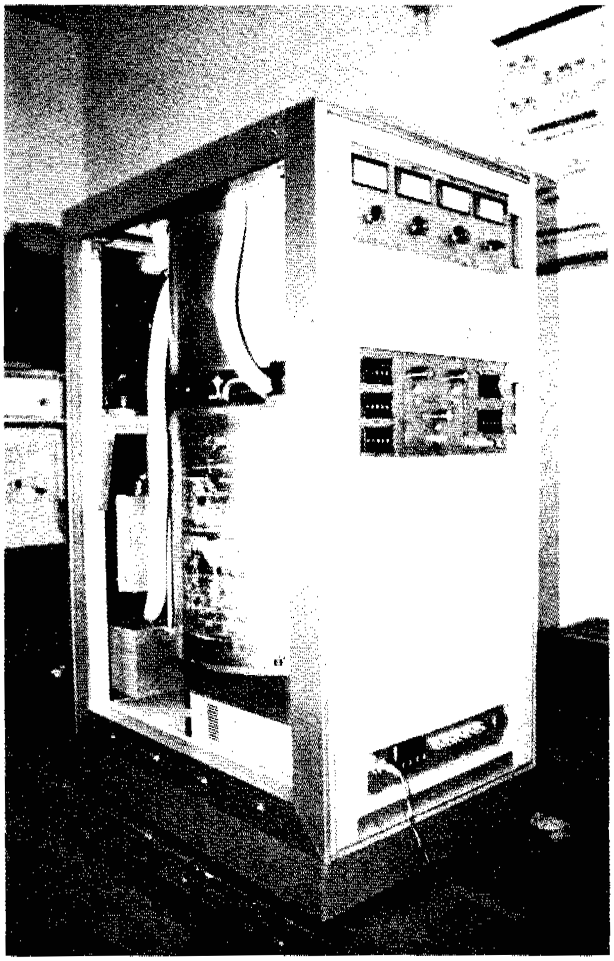

Fig 1 New Hydrogen Maser

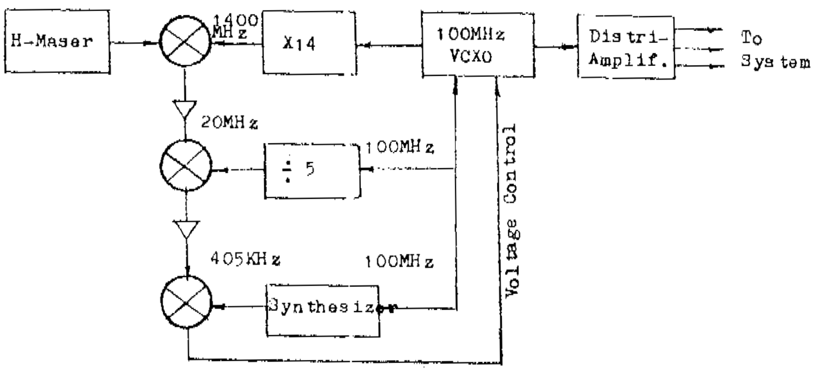

Fig 3 Maser clock system block diagram

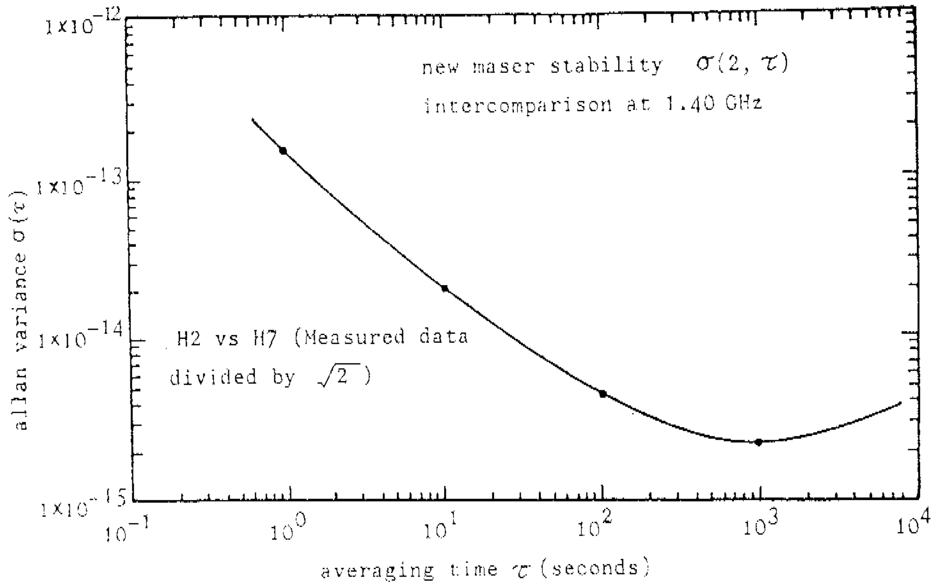

Fig.4 New maser stability data

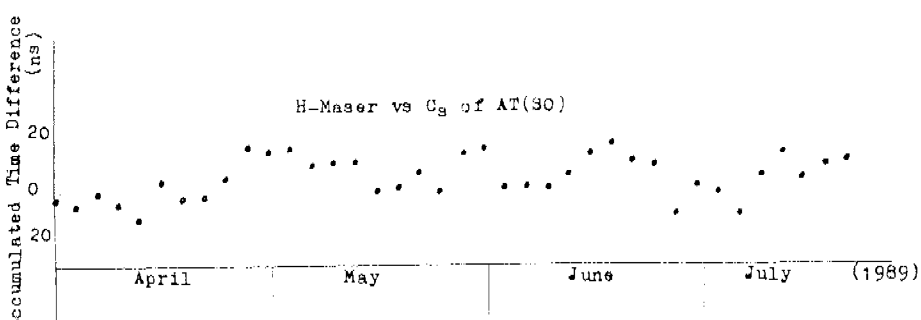

Fig 5 Accumulated Time Difference of H-C_s

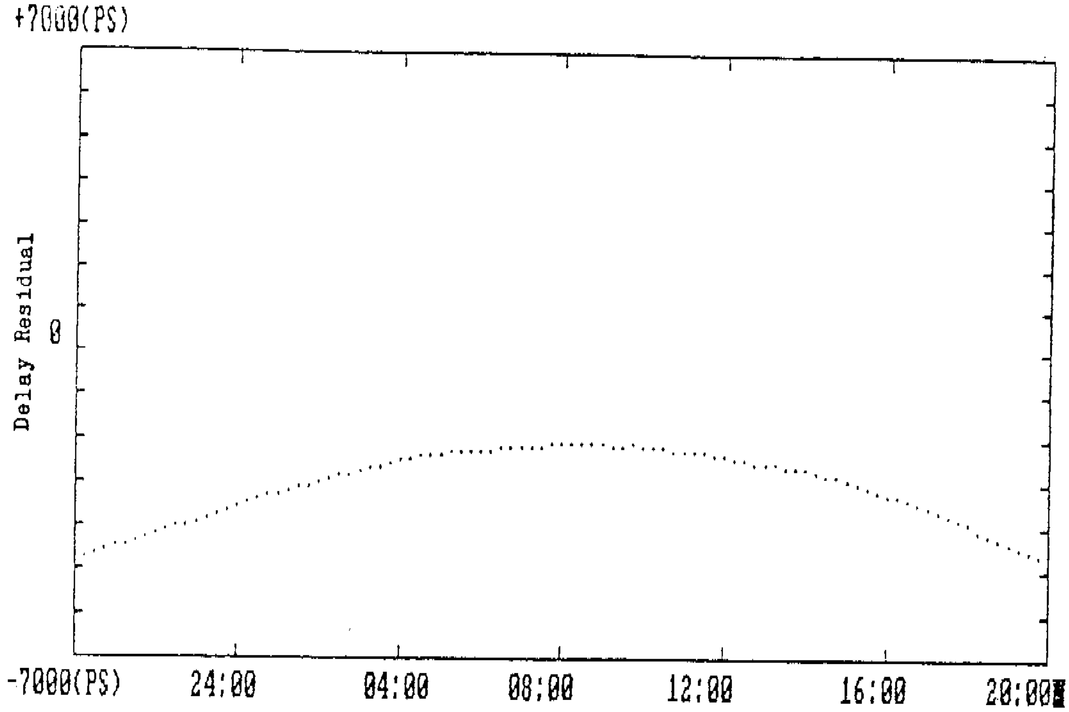

Fig.6 VLBI Phase Comparison With Frequency Offset Removed

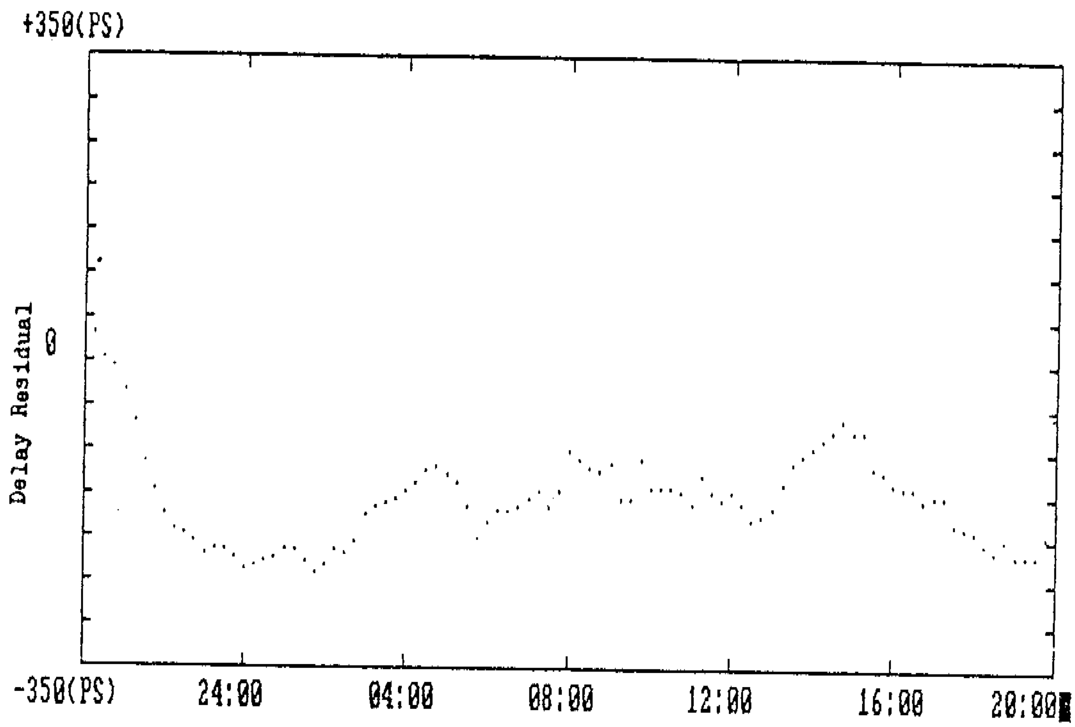

Fig.7 VLBI Phase Comparison With Frequency Drift Removed