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A KIND OF SMALL HYDROGEN MASER FOR TIME-KEEPING

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ABSTRACT

A kind of small hydrogen maser standard for timekeeping is being developed at Shanghai Observatory. The maser employs a cylindrical capacitively loaded cavity construction, resulting in significant size and weight reduction compared to a traditional hydrogen maser. The Q of the compact cavity is electronically enhanced by a suitable positive feedback into the cavity to enable sustained maser oscillation. The long-term stability of the maser is improved by a cavity frequency stabilization servo system. This paper describes the design and development of the maser, as well as photographs of the new maser system during the construction phase.

INTRODUCTION

After the success of the first Chinese hydrogen Maser made at Shanghai Observatory in 1972, 5 more hydrogen Masers with several improvements to the maser design were made at Shanghai Observatory for VLBI observations and for time-keeping. These hydrogen Masers are conventional laboratory standards. [1]

To equip chinese VLBI network, a new generation of hydrogen maser, a integrated, rugged and easily transportable maser, was developed successfully in 1987. [2,3] And so far 6 this kind of hydrogen masers have been put to use in chinese VLBI network and in military [4,5]

At present, Shanghai Observatory meanwhile is developing the third generation of hydrogen maser, a Q-enhanced maser, which employs a compact cavity design, resulting in significant size and weight reductions compared to a conventional maser. The long-term stability for this kind of maser is improved by a cavity frequency stabilization servo system. This paper describes the design and development of the Q-enhanced hydrogen maser, as well as photographs during the construction phase.

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OPERATION PRINCIPLE [8]

The operation principle of a Q-enhanced maser oscillator is shown in Figure 1. Similar to a conventional maser, a state-selected beam of hydrogen atoms is focused into a storage bulb placed inside a compact cavity tuned to the hyperfine transition frequency of ground-state hydrogen atoms. The interaction of the atoms with the cavity electromagnetic field causes the atoms to radiate. The losses in the compact cavity are such that the maser oscillation condition is difficult to satisfy. This limitation is overcome by positive feedback, as shown in Fig 1. A portion of the externally amplified maser output is fed back into the cavity. The attenuation in the feedback loop determines the amount of feedback, while the phase shifter adjusts propagation delays to ensure that the feedback signal is in phase with the electromagnetic field in the cavity. Thus, the cavity losses are effectively reduced or cavity Q-enhanced and sustained maser oscillation can be obtained.

However, the cavity in a Q-enhanced oscillator is not an isolated component as in a conventional maser. The cavity resonance frequency is sensitive to phase shift in the feedback loop. In fact, the cavity and the feedback loop form a resonant system that is susceptible to environmental perturbations. It is therefore essential to have a cavity frequency stabilization servo system.

MASER OSCILLATOR SYSTEM

The physics unit of the Q-enhanced maser is shown in Fig 2. The mechanical structure except for the cavity is similar to a conventional maser. The vacuum chamber is made of aluminum and is connected to the source manifold by a titanium tube which provides mechanical support with low thermal leakage to the cavity interaction region. Vacuum maintenance is provided by 70 l /s ion pump, as shown in Fig 3. The source of the state-selected atomic hydrogen beam, consisting of an rf dissociator and a hexapole magnet, is fabricated as the conventional design. The solenoid is made of multi-layer printed circuit design, allows very complete cancellation of spurious magnetic field and provides a rugged, close-fitting, and simple coil system which is equipped with two end field gradient correction coils driven from the same current source as the main coil. Magnetic shielding is provided by four layers of concentric cylindrical shields with conical end caps as shown in Fig 4.

The cavity consists of a section of 15cm O.D. × 5mm wall × 15cm long aluminum tubing with aluminum end plates. Input and output coupling loops as well as a varactor reactance tuner are mounted on the bottom end plate. For tuning the frequency of the cavity, a big mechanical piston inside the cavity is mounted on the top end plate. The storage bulb, 10cm O.D. × 11cm long, provides mechanical support for the cylindrical loading capacitor. The capacitor consists of four equally spaced electrodes fabricated from 0.5mm thick ×6cm wide×11cm long copper shims and attached to the bulb by epoxy. The bulb is coated on the inside surface with F46 Teflon by standard techniques. The loaded carity Q is about 5000. Fig 5 shows the cavity-storage bulb subassembly.

Separate temperature controls are provided at the dome, cyinder, and base sections of the vacuum chamber as well as at outoven aluminum cylinder located the outside of the second layer of the magnetic shields. To minimize DC stray fields, double bifilar heater windings and DC heater currents are used. Fig 6 shows under assembling of the maser oscillator.

ELECTRONICS SYSTEM

As mentioned above, the cavity and the feedback loop form a resonant system that is susceptible to environmental perturbations. It is therefore essential to have a cavity frequency stabilization servo system. As shown in Fig 7, if the desired cavity frequency is fo, then two test signals of equal amplitude at frequencies f_1 and f_2 symmetrically situated with respect to fo and at half-power points of the cavity response will be alternately injected into the cavity by square wave modulating the test signal source. If the cavity response is represented by the solid curve in Fig 7, then the rectified test signals have the same amplitude and there would be no error signal at the modullating frequency. On the other hand, if the cavity has drifted so that the response is represented by the dotted curve, cavity transmissions at frequency f_1 and f_2 are quite different. The rectified test signals produce a square wave at the modulating frequency. This error signal is synchronously detected and additional gain is provided by a smoothing integrator, the output of which is used to bias the varactor reactance tuner so that the cavity response is slewed back to the desired solid curve.

A functional block diagram of Q-enhanced maser signal-processing system is shown in Fig 8. The cavity Q enhancement and frequency stabilization servo are located, respectively, in the central portion and in the left side of the diagram. The front end microwave electronics is common to both systems. After the first conversion, the signal is divided into two channels by a power-divider. In one channel, a narrow crystal band pass filter (BW=3KHZ) passes maser oscillation signal to the clock signal processing circuits. In the other channel, the signals are rectifed and synchronously detected for the cavity stabilization servo system. To minimize interference with radiating atoms due to switching sidebands, the test signal synthesizer is switched to generate alternately the two test frequencies at a relatively low rate of 1HZ. The spacing of the frequencies f_1 and f_2 is selected to be 30KHz since strong maser oscillation could be obtained with an enhanced cavity width of that magnitude.

What we should mention is that except for the front-end components, the signal-processing electronics is housed in a rack seperate from the physics unit. A thermal control unit is used to regulate the temperature of an aluminum box in which the front-end microwave electronic components are mounted These components include the feedback loops and the integrator that drives the reactance tuner The box location is chosen to minimize the length of the transmission line used in maser input-outgoing coupling. Fig 9 shows the maser electronics system including the cavity stabilization servo. [7]

THE LAST WORD

In the sections above, we described the design and development of a small oscillating compact hydrogen maser at Shanghai Observatory as well as some photographs during the construction phase At present, the maser is under assembling and testing. Hopefully we can obtain some data at the beginning of the next year.

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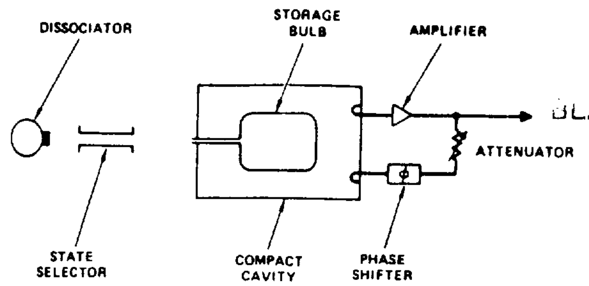

Fig. 1 Schematic of a Q-enhanced maser oscillator

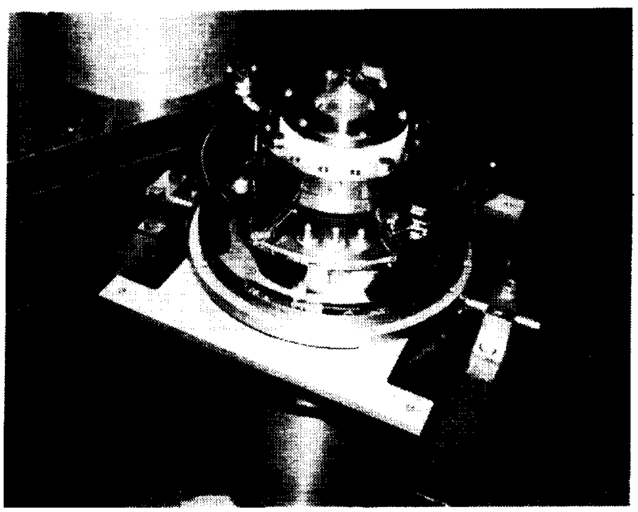

Fig. 2 The photograph of a Q-enhanced maser oscillator system

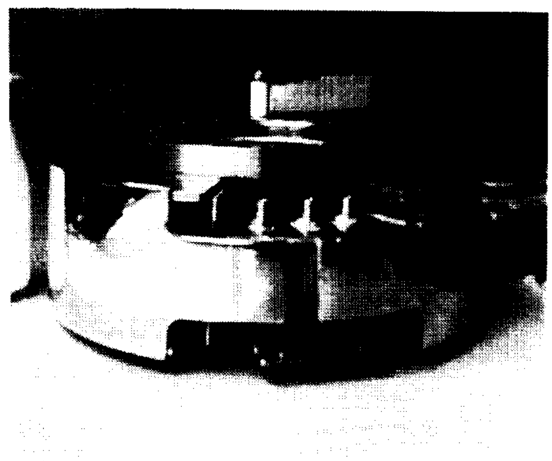

Fig. 3 The photograph of a small size Ion pump

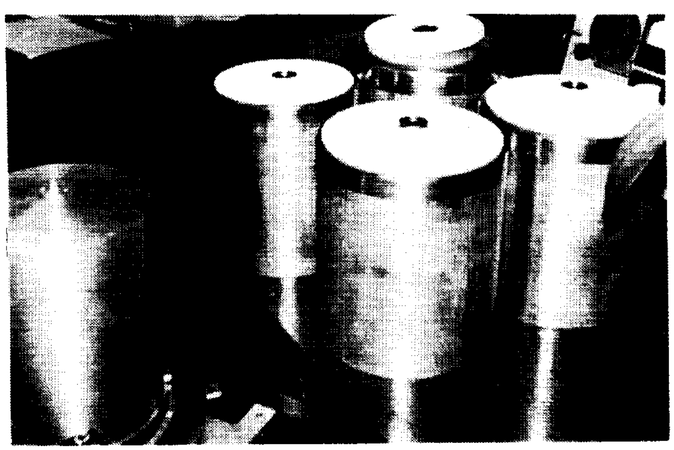

Fig 4 The photograph of magnetic shielding with conical end caps.

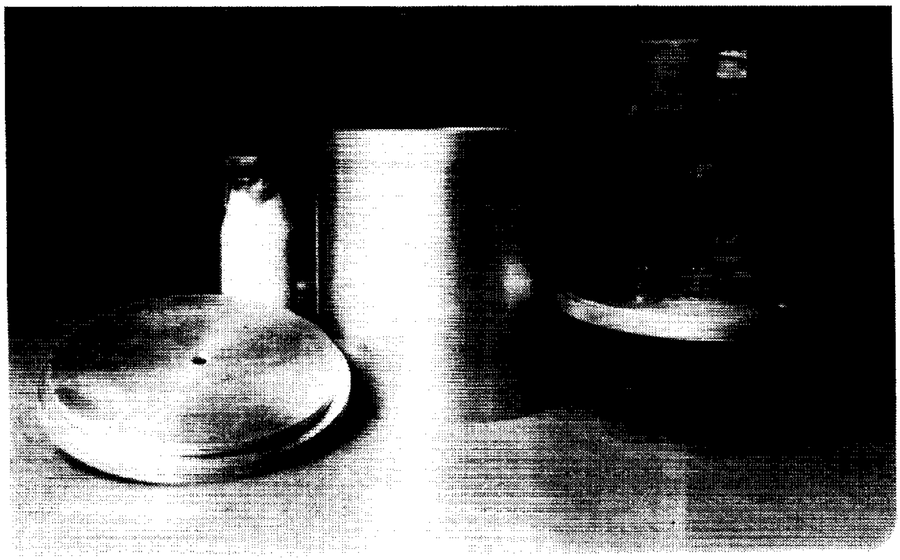

Fig 5 The photograph of compact cavity-bulb structure

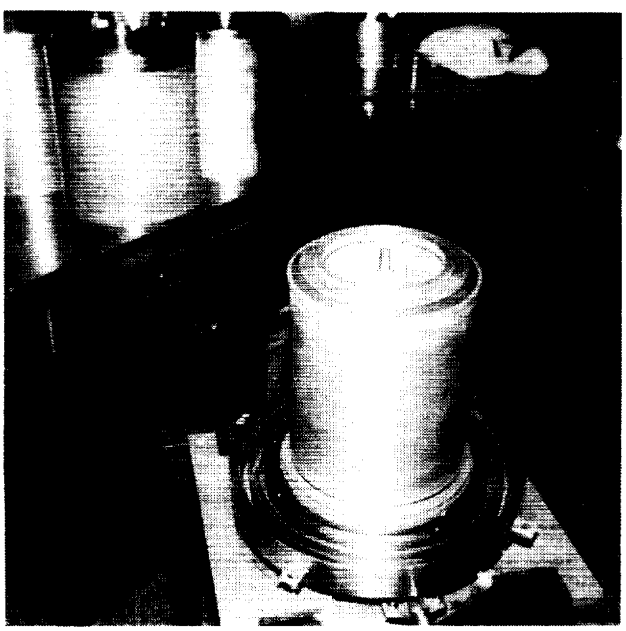

Fig 6 The maser oscillator system
under assembling

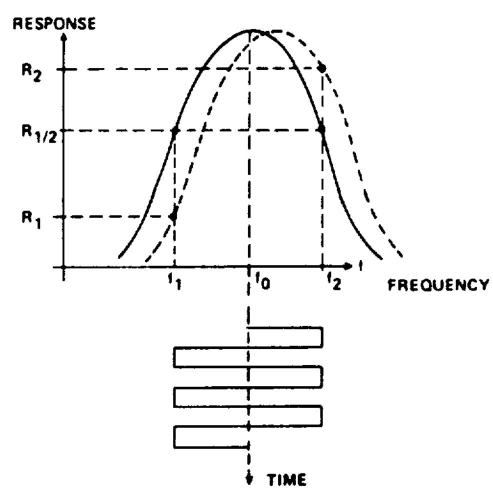

Fig 7 concept for cavity freguency
stabilization servo system

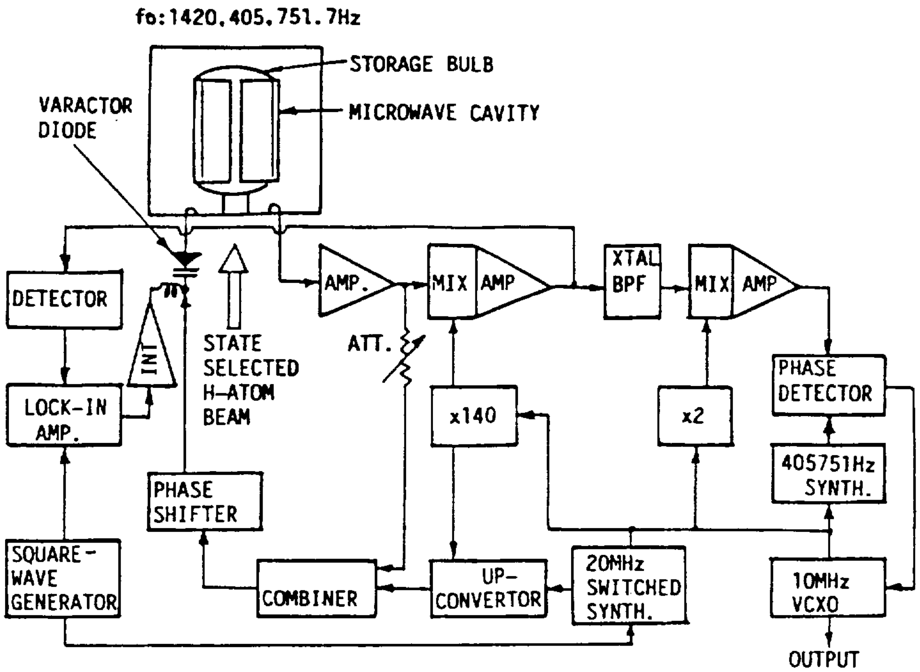

Fig 8 Functional block diagram of Q-enhanced maser oscillator with cavity stabilization servo system

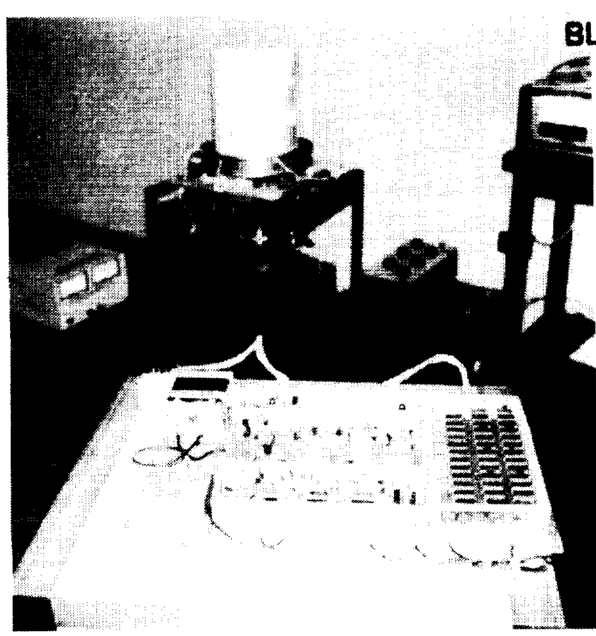

Fig. 9 The photograph of Q-enhanced maser electronics system