Development of passive hydrogen maser in Shanghai Astronomical Observatory

24th European Frequency and Time Forum
13-16 April 2010

Xie Yonghui[1], Dai Jiayua[1], Chen Wenxing[1], Liu Tiexin[1], Zhang Yong[1], Pen Jixing[1], Lin Chuanfu[1]

[1]*Shanghai Astronomical Observatory*

200030, 80 Nandan Road, Shanghai, CHINA

Email:xyh@shao.ac.cn

Abstract: Study of passive hydrogen maser in Shanghai Astronomical Observatory is introduced. New type of passive hydrogen maser with high performance has been developed. It has unique features such as novel kind of electrode cavity with high Q factor (loaded-cavity Q factor up to 10000) and new frequency control scheme of electronics package, with the help of novel cavity-bulb assembly, quadrupole state selector, nickel purifier, new dissociator and four layer magnetic shield, the atomic signal gain of physics package is up to 3dB at -80dBm microwave signal input. Several passive hydrogen maser prototypes have been developed. Preliminary performance test yields the frequency stability better than 1×10-12τ-1/2(1s≤τ≤10000s) and 1×10-14 @1day.

I INTRODUCTION

Passive hydrogen maser has better performance than rubidium clock. Its long term frequency stability is comparable with cesium clock and short term frequency stability is better. It also featured as relatively light weight and long life time. Hence it is suitable for miniature time keeping. Shanghai Astronomical Observatory has devoted to development of hydrogen maser for a long period, since 2002 study on passive hydrogen maser had been carried out. Now 2 passive hydrogen maser prototypes have been developed. Appliance of new technology such as novel electrode microwave cavity, getter pump, nickel purifier and new dissociator has improved the performance and reduced weight of the physics package. Electronics package has induced time-separated control method for the two control loop of passive hydrogen maser, which is benefit to short term and middle term frequency stability. The measured frequency stability is better than $1\times10^{-12}\tau^{-1/2}$($1s\leq\tau\leq10000s$) and 1×10^{-14} @1day.

II PHYSICS PACKAGE

Since the limit of volume and weight, we can not employ the standard TE011 microwave cavity for passive hydrogen maser. So it is prevail in the world to use magnetronic cavity instead[1][2], in which metal plates form induction-capacitance structure to induce microwave resonance for stimulated emission. According to the fundamental theory of slotted tube cavity for rubidium clock[3], we have designed a novel kind of electrode cavity for passive hydrogen maser, as shown in fig. 1.

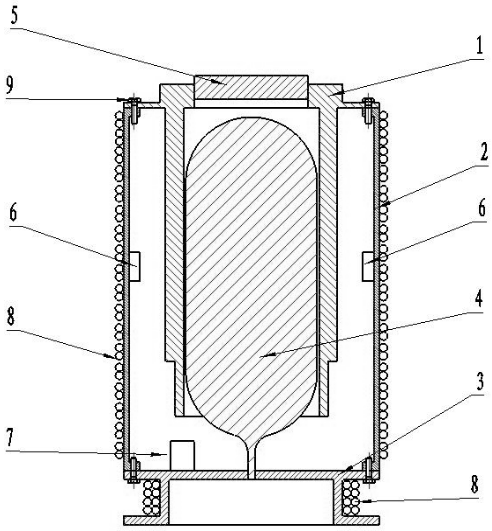


Fig. 1. structure of electrode cavity for passive hydrogen maser，

1：electrode tube；2：cylinder cavity；3：base plate；4：storage bulb；5：frequency adjust knob；6：coupling loop；7：varactor diode loop；8：thermal control coil

Structure of electrode tube is shown in fig. 2. Several electrodes are firmly fixed on top flange, and gaps occur between electrodes. Electrodes and gaps form the necessary induction-capacitance structure.

Microwave field in the electrode cavity can be simulated by computer software, as is shown in fig. 3. In the storage bulb region where stimulated emission take place, Microwave field is uniform and parallel to the C-field, meaning that this cavity is very suitable for hydrogen atoms stimulated emission. And the filling factor given by the simulation is about 0.5.

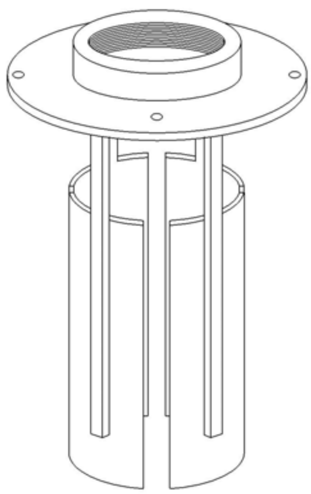


Fig. 2. Structure of electrode tube

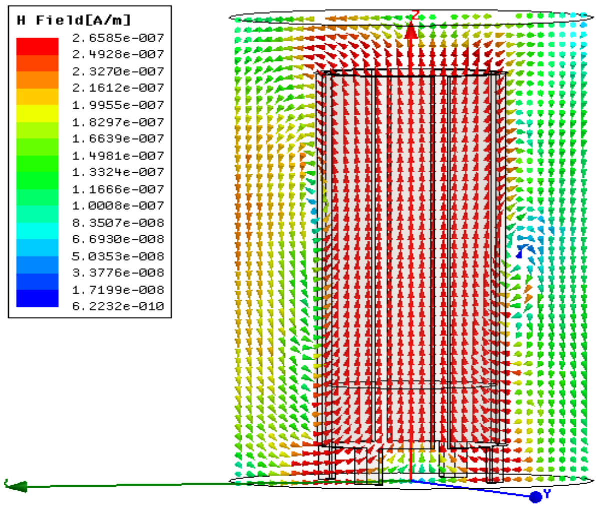


Fig. 3. microwave field in the cavity

The produced electrode cavity exhibit excellent performance, its loaded Q factor is up to 10000, 10% better than magnetronic cavity, while the weight is 20% lighter.

According to the structure of physics package, getter pump with corresponding interface is designed. Getter matter is domestic made, whose absorption capacity is up to 20L at normal pressure, and the vacuum is kept below 10^{-4}Pa.

Hydrogen source is stored by solid method. 20L hydrogen gas at normal pressure, which is sufficient for 8 years normal operation, is stored in metal material, and storage pressure is about 1.4MPa, much safer than traditional method. Palladium purifier is taken place by nickel purifier, which has higher stability of hydrogen flux control and lower hydrogen wastage when the maser is in standby mode. The diameter of nickel tube is 1mm. Hydrogen molecules are dissociated into atoms by 100MHz RF produced by a new dissociator, whose electronics and structure are redesigned and thermal conduct passage is improved. Temperature of discharge bulb in operation is kept below 60℃, even the cooling fan could be omitted. Hydrogen atoms in proper state are focused into storage bulb by quadrupole selector, magnetic induction at the pole top is about 1T. There are 4 layers of magnetic shield in the physics package, ensure a shield factor up to 50000.

Application of those technologies, the physics package of passive hydrogen maser has manifested good performance, the atomic signal gain of physics package is up to 3dB at -80dBm microwave signal input, as shown in fig. 4.

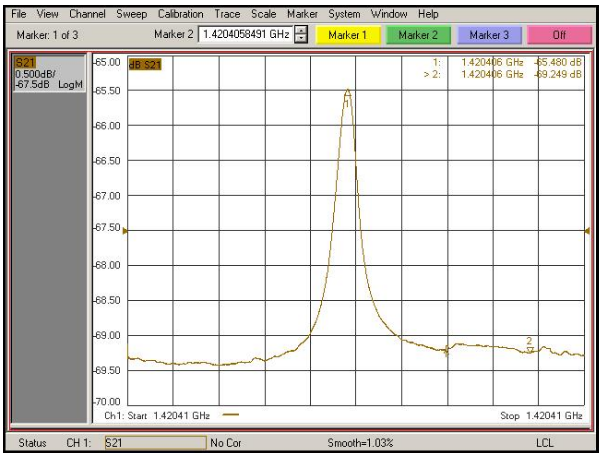


Fig. 4. Atomic signal gain of physics package at -80dBm microwave input

III ELECTRONICS PACKAGE

Electronics package of passive hydrogen maser has employed time-separated control method for the two control loop. Block-diagram is shown in fig. 5.

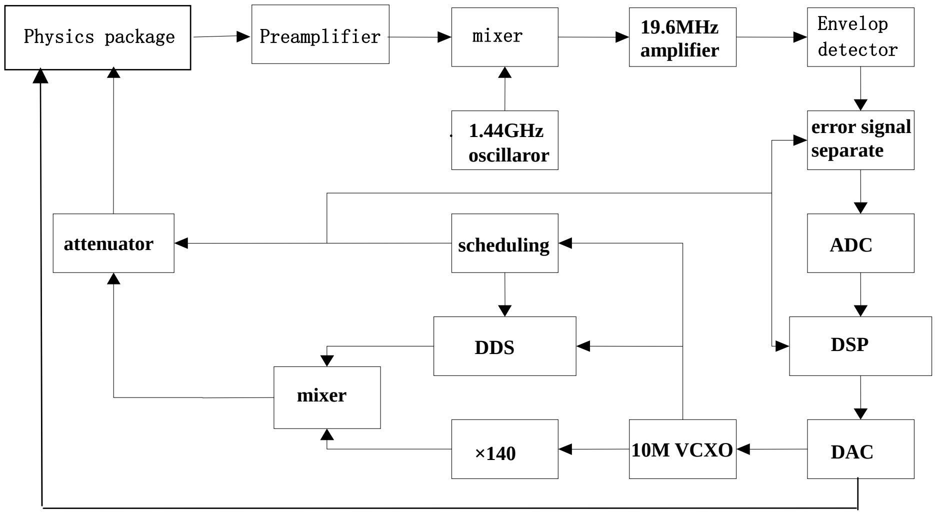
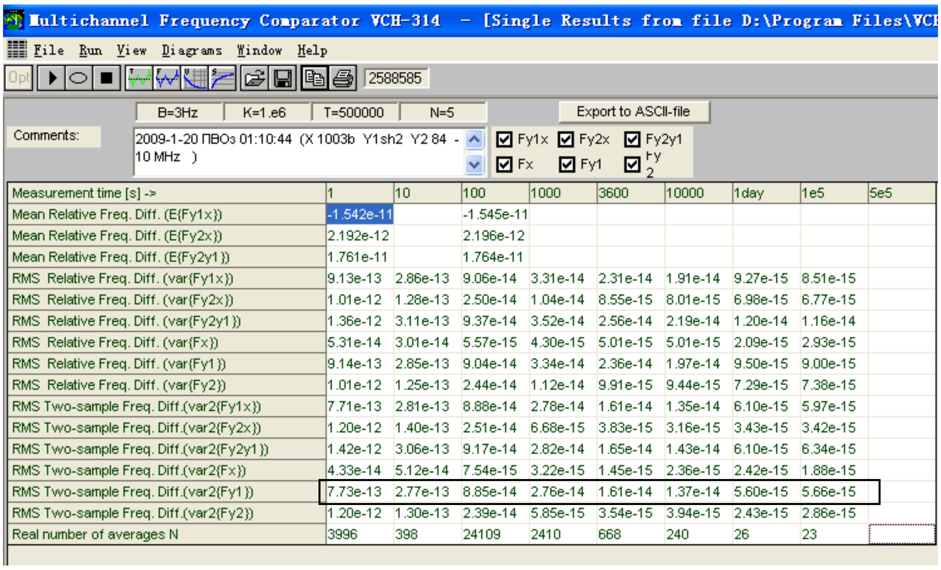


Fig. 5. Block-diagram of electronics package

In the control of 10MHz VCXO, Scheduling module produce scheduling signal, which determine working state of the control loops. 20.405MHz signal produced by DDS is frequency modulated and mixed with 1400MHz signal which is multiplied by 10MHz VCXO signal, getting 1420.405MHz as interrogation signal and sending into physics package. Carrier wave frequency of interrogation signal for the two control loop is the same, but modulation frequency and modulation index are different. Corresponding error signals are induced by the physics package according to the modulation frequency and modulation index. These error signals are time separated and can be divide into to ways. After computation of DSP the error signals form control signals for VCXO and varactor respectively.

IV PERFORMANCE TEST

Physics package and electronics package are integrated and optimized. Then we have tested the performance. Frequency stability is tested by frequency comparator VCH-314 and the reference clock is two active hydrogen masers. The test last for 26 days without interruption. Result shows that the frequency stability of passive hydrogen maser is up to $1\times10^{-12}\tau^{-1/2}$($1s\leq\tau\leq10000s$) and 1×10^{-14} @1day, as shown in fig. 6. The temperature coefficient is measured as 5×10^{-14} /℃.



Measurement time [s] ->	1	10	100	1000	3600	10000	1day	1e5	5e5
Mean Relative Freq. Diff. (E{Fy1x})	-1.542e-11		-1.545e-11						
Mean Relative Freq. Diff. (E{Fy2x})	2.192e-12		2.196e-12						
Mean Relative Freq. Diff. (E{Fy2y1})	1.761e-11		1.764e-11						
RMS Relative Freq. Diff. (var{Fy1x})	9.13e-13	2.86e-13	9.06e-14	3.31e-14	2.31e-14	1.91e-14	9.27e-15	8.51e-15	
RMS Relative Freq. Diff. (var{Fy2x})	1.01e-12	1.28e-13	2.50e-14	1.04e-14	8.55e-15	8.01e-15	6.98e-15	6.77e-15	
RMS Relative Freq. Diff. (var{Fy2y1})	1.36e-12	3.11e-13	9.37e-14	3.52e-14	2.56e-14	2.19e-14	1.20e-14	1.16e-14	
RMS Relative Freq. Diff. (var{Fx})	5.31e-14	3.01e-14	5.57e-15	4.30e-15	5.01e-15	5.01e-15	2.09e-15	2.93e-15	
RMS Relative Freq. Diff. (var{Fy1})	9.14e-13	2.85e-13	9.04e-14	3.34e-14	2.36e-14	1.97e-14	9.50e-15	9.00e-15	
RMS Relative Freq. Diff. (var{Fy2})	1.01e-12	1.25e-13	2.44e-14	1.12e-14	9.91e-15	9.44e-15	7.29e-15	7.38e-15	
RMS Two-sample Freq. Diff.(var2{Fy1x})	7.71e-13	2.81e-13	8.88e-14	2.78e-14	1.61e-14	1.35e-14	6.10e-15	5.97e-15	
RMS Two-sample Freq. Diff.(var2{Fy2x})	1.20e-12	1.40e-13	2.51e-14	6.68e-15	3.83e-15	3.16e-15	3.43e-15	3.42e-15	
RMS Two-sample Freq. Diff.(var2{Fy2y1})	1.42e-12	3.06e-13	9.17e-14	2.82e-14	1.65e-14	1.43e-14	6.10e-15	6.34e-15	
RMS Two-sample Freq. Diff.(var2{Fx})	4.33e-14	5.12e-14	7.54e-15	3.22e-15	1.45e-15	2.36e-15	2.42e-15	1.88e-15	
RMS Two-sample Freq. Diff.(var2{Fy1})	7.73e-13	2.77e-13	8.85e-14	2.76e-14	1.61e-14	1.37e-14	5.60e-15	5.66e-15	
RMS Two-sample Freq. Diff.(var2{Fy2})	1.20e-12	1.30e-13	2.39e-14	5.85e-15	3.54e-15	3.94e-15	2.43e-15	2.86e-15	
Real number of averages N	3996	398	24109	2410	668	240	26	23	

Fig. 6. frequency stability test result of passive hydrogen maser, y1 is result of passive hydrogen maser， x and y2 is result of active hydrogen maser

V CONCLUSION

Study on passive hydrogen maser at Shanghai Astronomical Observatory is carried on since 2002. Now 2 passive hydrogen maser prototypes have been developed, which introduce many efficient technologies such as novel electrode cavity with high Q factor, time separate control loop scheme, quadrupole state selector, nickel purifier, new dissociator and four layer magnetic shields. The performance is greatly improved, frequency stability now is up to $1\times10^{-12}\tau^{-1/2}$($1s\leq\tau\leq10000s$) and 1×10^{-14} @1day. We are still optimizing parameters of the prototypes and the performance is hopeful to be further improved.

REFERENCES

[1]N.A.Demidov, A.A.Belyaev, B.A.Sakharov, and A.A.Uljanov, “Passive hydrogen maser frequency stability and accuracy investigation,” 7th EFTF Meeting, Neuchatel, 1993.

[2] Qinghua Wang, Pierre Mosset, Fabien Droz, and Pascal Rochat, “Verification and ptimization of the physics parameters of the onboard galileo passive hydrogen maser,” 38th PTTI Meeting, Washington, pp.1-13, 2006.

[3] Mei Ganghua, Zhong Da, and An Shaofeng, “Miniatured microwave cavity for atomic frequency standard,” US Patent: 6 225 870 B1, 2001.