A Subminiature Microwave Cavity for Rubidium Atomic Frequency Standards

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***Abstract*—A subminiature microwave cavity for rubidium atomic frequency standards has been developed. The cavity has volume of 8.1 cm^3, and is of strong resonant signal with high Q factor. Based on the cavity a small size cavity-cell assembly with volume of 9.5 cm^3 for rubidium frequency standards has been developed. A preliminary test showed that the cavity-cell assembly is of ability to achieve a short-term frequency stability of $3\times10^{-11}/\sqrt{\tau}$.**

I. INTRODUCTION

Miniaturization is one of the major topics for researches of passive rubidium atomic frequency standards (RAFS). The RAFS is primarily composed of a physics package acting as frequency discriminator and a frequency locking loop circuit. As the development of electronic technology, electronics can be made very small, thus main difficulty for miniaturization of RAFS lies in physics package especially the cavity–cell assembly in which.

The cavity-cell assembly consists primarily of a microwave cavity and a rubidium cell. The rubidium cell is inside the microwave cavity, thus the size of the cavity determines the volume of the whole cavity-cell assembly. The TE_{011} cavity is the earliest one to be introduced in RAFS. Due to its large volume, however, the TE_{011} cavity was soon replaced by the TE_{111} cavity. In some applications the TE_{111} cavity is still too large. To reduce the cavity volume further, many efforts have been made. Researches were carried out along two technical lines. One is to load a conventional microwave cavity with material with high relative dielectric constant. For example, the Fujitsu loaded the TE_{111} cavity with alumina ceramic that has a relative dielectric constant of about 10, and obtained a cavity with volume of 9.7 cm^3 [1]. The other one is to develop non-standard cavities, typical works include the loop-gap cavity introduced by Froncisz et al. [2], the magnetron cavity by Schweda et al. [3], and the slotted tube cavity by our laboratory [4].

Our previous slotted tube cavity has a volume of 15 cm^3 [4]. Based on modification of the cavity, a new version of the cavity with volume of 8.1 cm^3 was developed recently in our laboratory. Afterwards a cavity-cell assembly for RAFS was made, in which the integrated filtering technique (IFT) was utilized. A preliminary test showed that the cavity-cell assembly is of ability to achieve a short-term frequency stability of $3\times10^{-11}/\sqrt{\tau}$, close to typical performance for commercial RAFS. In this paper, we report the structure and characteristics of the microwave cavity and the related test results.

II. STRUCTURE OF THE MICROWAVE CAVITY AND CAVITY-CELL ASSEMBLY

This cavity is composed of a slotted tube, a cylindrical cavity body, a dielectric ring and an upper cap. The cavity-cell assembly is constructed by adding the cavity with a rubidium absorption cell, a C-field coil, a heating coil, a photocell, a coupling loop and a magnetic shielding. Fig. 1 shows the structure of the cavity-cell assembly.

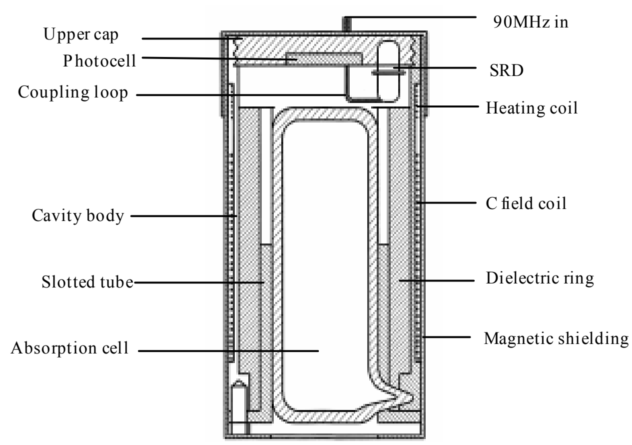

Figure 1. Structure of the IFT cavity-cell assembly

The core of microwave cavity is the slotted tube. The geometric parameters of the slotted tube determine the resonant frequency of the cavity and distribution of microwave field inside the cavity. The cavity-cell assembly was designed by using the IFT scheme. The absorption cell was placed inside the slotted tube. A dielectric ring with relative dielectric constant of about 2.5 was inserted between the cavity body and the slotted tube to increase the effective volume of the cavity and to ensure rigidity of the cavity-cell assembly. The photocell was installed on the inner side of the upper cap for light detection. Microwave signal was sent into the cavity through the coupling loop. The step recovery diode (SRD) was for purpose of microwave frequency multiplication. The C-field coil and the heating coil were wound on the outer surface of the cavity body. The magnetic shielding was installed touching the cavity body to reduce the whole volume of cavity-cell assembly. A hole is made on the bottom cap of magnetic shielding to allow light from rubidium spectral lamp to pass through.

The structure of slotted tube is shown in Fig. 2. It provides a capacitive-inductive structure with 8 electrodes and slots. Properties of the microwave cavity are mainly determined by geometric parameters of the capacitive-inductive structure. The parameters include the length L_1, the thickness t, the width w of the slot, and the length L_2, the radius r of the slotted tube. Volume of the cavity is given by the radius and the length of the cavity body, but the decrease of both parameters will be limited by the size of the slotted tube. Thus the key to achieve a miniature slotted tube cavity is to reduce the L_2 and the r of the slotted tube, meanwhile to keep the resonance frequency of cavity unchanged.

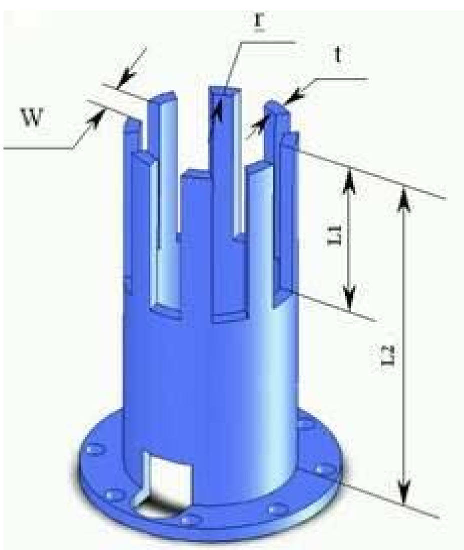

Figure 2. Structure of the slotted tube

We investigated the dependence of resonance frequency on the geometric parameters of the slotted tube [5]. It was found that the resonance frequency is not sensitive to L_1 and w, but very sensitive to L_2. Hundreds megahertz decrease of resonance frequency would be caused by 1mm increase of L_2. This feature makes it possible for us to reduce the cavity volume further. As the first step, we reduced greatly the radiuses of the cavity body and the slotted tube. Such a measure caused a considerable increase of cavity resonance frequency. Secondly, to compensate the increase of the cavity resonance frequency, we made an increase of L_2, and found that a slight increase of L_2 is enough for the compensation. In addition, the increase of L_2 enables us to use a longer dielectric ring. This would lead a decrease of cavity frequency also. As the net effect of measures above, the cavity volume is remarkably reduced, and resonance frequency still maintain to 6834MHz, which is the frequency of rubidium clock transition. The final volume of the cavity is 8.1 cm^3.

The thickness of cavity body has no effect on the properties of cavity. But redundant thickness of cavity body would increase both the volume of cavity and thermal power consumption of the cavity-cell assembly. In our design, the thickness of cavity body was chosen as 0.5mm, and the volume of the whole cavity-cell assembly is about 9.5cm^3

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Resonance property of the cavity

With all parts including the absorption cell loaded in the cavity, the resonance profile of the cavity was measured. The result is shown in Fig.3. The cavity had a strong absorption line with Q factor of about 400 at 6834MHz. The result indicates that the cavity is of excellent frequency selection characteristic. Compared with the result of our previous cavity with volume of 14.7 cm^3 [5], the resonance property of the present cavity keeps nearly unchanged.

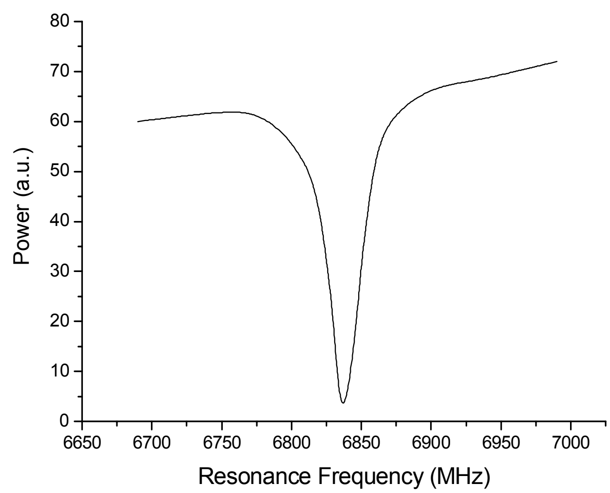

Figure 3. Profile of the cavity resonance line

B. Frequency Stability

A desk prototype of physics package was developed by using the subminiature cavity-cell assembly. The physics package was connected with electronics to form a desk RAFS unit, and frequency locking was realized. A preliminary test showed that the RAFS had a short-term frequency stability of $3\times10^{-11}/\sqrt{\tau}$, similar to typical performance of a commercial RAFS.

The cavity-cell assembly was designed in IFT scheme. The diameter of the used absorption cell was only 10mm, smaller than commonly used. The test result of frequency stability implies that the cavity-cell assembly is still of acceptable signal to noise ratio (SNR). There may be two reasons for the result. Firstly, in design of the slotted tube the number of slots was chosen as much as 8. According to Sphicopoulous' theory [6], the microwave field inside the slotted tube is excited by equivalent magnetic current flowing on the slots. Therefore a large number of slots would lead a large volume of microwave field filling inside the cavity. In this case more atoms could interact with microwave field, thus enhancing the atomic transition signal. Secondly, material with moderate dielectric constant was utilized to make the dielectric ring, so that the microwave field would not be so restricted inside the dielectric ring, and the distribution of microwave field inside the absorption cell still keeps uniform. This method helps to reduce the cavity volume meanwhile has no much negative effect on SNR of the physics package. Principally, if a dielectric material with very high dielectric constant like alumina ceramic is filled in a microwave cavity, significant reduce of cavity volume would be expected [1], but at the same time a cost to sacrifice SNR to some extent may be led.

The cavity-cell assembly shown in Fig. 2 could be easily transformed to an SFT (separated filter technique) one. One can do this by simply putting a filter cell and a shorter absorption cell into the slotted tube to take place of the absorption cell. A higher SNR could be expected by the improvement. The related work is under way.

IV. SUMMARY

The resonance frequency of the slotted tube microwave cavity is sensitive to geometrical parameters of the slotted tube. By making use of this property, a subminiature version of the cavity with volume of 8.1 cm^3 has been developed. Results and analysis show that the cavity is of intense resonance signal, high line Q and great microwave filling factor besides the small size. Based on the cavity a miniaturized IFT cavity-cell assembly was designed. The volume of the assembly is 9.5 cm^3, and the diameter of the used absorption cell is 10mm. A preliminary test showed that the cavity-cell assembly is of ability to achieve a short-term frequency stability of $3\times10^{-11}/\sqrt{\tau}$. Moreover, the cavity-cell assembly can be easily transformed to an SFT system. By this change of design a better frequency stability could be logically expected.

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