A SAPPHIRE COMPACT HYDROGEN FREQUENCY STANDARD

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This paper primarily introduces three parts of our sapphire compact hydrogen atomic frequency standard. Firstly, it mainly explains the operating principle of the active frequency standard. Secondly, it presents the major components of our device, which are pivotal technology of the compact hydrogen maser, such as cylinder resonant cavity, quadrupole magnetic state selector, high vacuum system, phase-lock receiver and cavity servo-circuit. Finally, it lists the primary performance of our compact hydrogen frequency standard.

1 the Principle of Operation

The block diagram of the compact hydrogen atomic frequency standard is given in Fig.1, which consists of quantum system and circuit system.

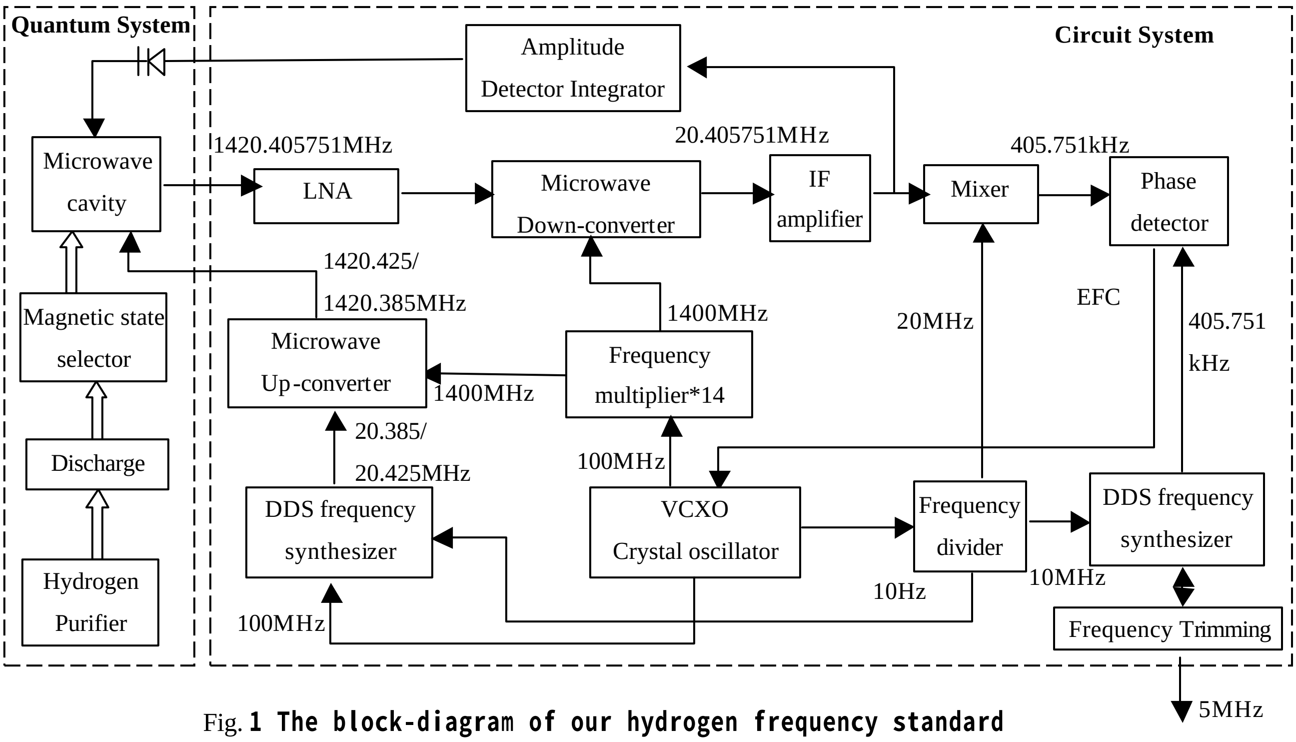

Fig. 1 **The block-diagram of our hydrogen frequency standard**

The compact hydrogen atomic frequency standard is an active frequency standard. It is based on quantum theory, produces quantum transition between two high atomic energy levels. Quantum system is a self-consistent oscillator. The frequency of output signal is excellent stability (1420.405751MHz). It has the aid of phase-lock technology to lock the frequency of crystal oscillator, in order that the surging frequency of crystal oscillator has the excellent stability of physical part, and can be used as signal of frequency standard.

2 Pivotal Technology

2.1 Resonant Cavity

It is a place where the hydrogen atoms interact with radiation field. It requests that Q value is high, resonant frequency is coherent with the atomic transition frequency. Electromagnetic field mode fits with tuning equipment; and has coupling equipment.

The compact hydrogen frequency standard uses a cylinder resonant cavity with the sapphire medium filled in. The medium resonant has many virtues such as small volume, less weight, high Q, simple and stable structure, stable and reliable performance. Here, the sapphire is not only used as storage bulb to storage hydrogen gas, but also as filling medium, that is to change the electromagnetic field characteristic in cavity, Q value, cavity volume.

We have deducted TE_{011} mode electromagnetic structure and relation between quality factor Q, resonant frequency f with cavity size, medium geometry size, medium characteristic. It is the theory basis to design microwave cavity.

According to theory derivation, we have designed microwave cavity. Sapphire medium's inner radius R_3 is 42mm; outer radius R_2 is 47mm; height L is 175mm. Metal cavity's inner radius R_1 is 176mm. The top of the sapphire has a piston to apply to the rough adjustment of microwave cavity resonant frequency.

2.2 Magnetic State Selector

The function of the magnetic state selector is to select high energy state hydrogen atoms needed by hydrogen frequency standard, and shoot them into the storage bulb, and to take out useless low energy state atoms along axis line by vacuum system.

We adopted the quadrupole magnetic state selector. It is one of the pivotal parts of quantum system. It has following features: small volume, strong selective ability. To design better, firstly we went on derivation from quantum theory basis. **Selective formula with quadrupole is as follows:** $\frac{u_B H_0}{3kTr_0}(\frac{l_2^2}{2}+l_2 l_3)=\delta\,(l_1+l_2+l_3)$.

Where, u_B **is Bol magneton,** k **is Boltzman constant,** r_0 **is magnetic gap radius. This formula** was a basis for design work of quadrupole magnetic state selector.

2.3 Vacuum system

New type vacuum system designed by us is constituted using five small column ion pumps, because the feature of quadrupole magnetic state selector is allowed to reduce volume of vacuum system. Due to using five small volume ion pumps, this is fully favorable for the "compaction of hydrogen frequency standard" .

2.4 Phase-Lock Receiver

The function and constitution of the phase-lock receiver have been presented already in the first section of the paper. But phase-lock loop parameter choice, circuit form design are very important, because they determine loop characteristics, effect short-period frequency stability of output 100MHz and 5MHz frequency standard, and also influence long-period frequency stability and accuracy of the hydrogen standard.

2.5 Cavity Servo-Circuit

The cavity servo-circuit is the most important unit. The microwave signal f_1, f_2 produced in the circuit are fed into microwave cavity. f_1, f_2 signals designed by us are about 20dB larger the maser signal.

To realize long-period stability 10^{-14} of the hydrogen atomic frequency standard, the servo system must control cavity frequency in a few Hz. The constitution principle is given in fig.2.cavity temperature factor charge.

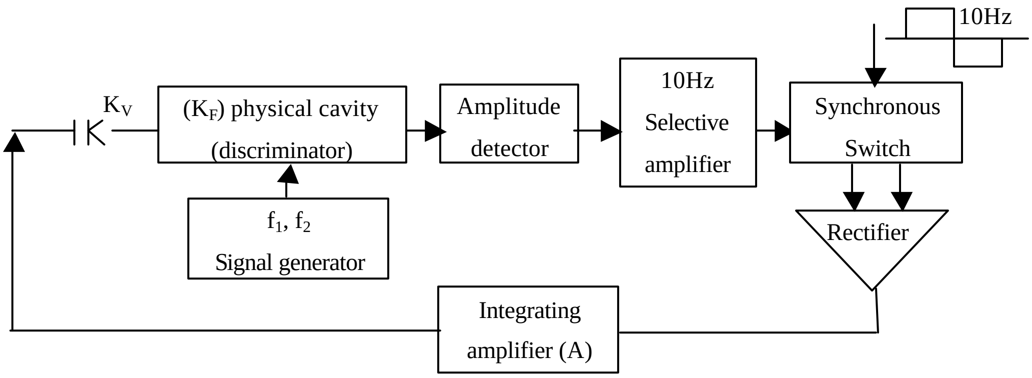

Fig.2. Block diagram of cavity frequency servo-system principle

The following is some considerations about specific design:

(1) To select selector fine temperature characteristics, linearity, high Q value, K_V: 2.5kHz/V.

(2) f_1, f_2 signal power to empty into discriminator bigger than that of hydrogen atom main spectrum line signal 10dB. F_1 and $f_2$can not too near main spectrum line of hydrogen maser, in order to eliminate frequency pulling as possible. Design choice distance to main spectral line is 20 kHz. Spectrum fed signal ought to be as pure as possibly, to make noise component near by hydrogen maser spectrum line is below hydrogen atom main spectrum line under 40dB.

(3) In AFC system, all circuits should made out low noise, low shift, high stable, to satisfy AFC system requirement.

(4) f_1, f_2 signals poured into discriminator are connected with resonant cavity, no employ ferrite isolator, but attenuator, thus both play necessary isolation and reduce more sensitive shortcoming of isolator to temperature charge.

3 Primary Performance Characteristics

Output frequency: 1Hz; 5MHz; 100MHz.

Frequency stability: $1.0*10^{-12}$/s; $2*10^{-13}$/10s; $8*10^{-14}/10^2$s; $4*10^{-14}/10^3$s; $2*10^{-14}$/1h.

Frequency accuracy: $\pm 1.5*10^{-12}$.

Phase noise: -97dBc/Hz,f=1 Hz; -145dBc/Hz,f=1k Hz.

Temperature range of operation: 10~30℃.

Volume: 500*380*600(mm).

Power: 144W.

Weight: 55kg.

Conclusion

The development of compact hydrogen atomic frequency standard is an important work. The stability of frequency standard we are developing up to the foreign produce level. Its volume will be reduced to 350*330*500(mm) that is what we are doing now.

Reference

1. Wang Yiqiu etc,<Quantum Frequency Standard Principle>,*Scientific Publishing House*, 1986

2. Shen Zhiyuan,<Microwave Technique>, *National Defense Industry Publishing House*,1980