DEVELOPMENT OF THE NEW MODEL INDUSTRIAL PASSIVE HYDROGEN MASER FREQUENCY AND TIME STANDARD VCH-1006

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1. ABSTRACT

New model of low cost industrial passive hydrogen maser frequency and time standard model VCH-1006 has been developed by "Vremya-CH" JS company for the last two years. The instrument is intended for use as a precision frequency and time reference at the metrological centers and telecommunication digital networks. New original technical and technological decisions permitted to reach the highest characteristics of frequency stability and reliability.

Keywords: Hydrogen maser, frequency stability.

2. INTRODUCTION

Passive hydrogen maser frequency and time standards having relatively smaller size in compare with the active hydrogen masers, hold the best frequency stability. Passive H-maser model VCH-1004, developed and produced by "VREMYA-CH" company demonstrated frequency stability from 1 x 10 $^{-12}$ up to 1 x 10 $^{-14}$ for 1 day and successfully used in several metrological centers as time and frequency reference or transportable clock.
Since 1999 passive hydrogen maser took the new application field in digital telecommunication networks as a primarily reference clock. In compare with Cs tube frequency standards, traditionally used for this purpose, VCH-1004 had better accuracy, frequency reproducibility and lifetime, but from other side this H-maser model was quite complicated and had relatively high cost.
New "VREMYA-CH" passive H-maser model VCH-1006, containing the newest original technical decision both in the design of quantum discriminator and in the electronics, combines the highest frequency stability, reliability, and low price of the instrument.

3.DESIGN PRINCIPLES OF VCH-1006 HYDROGEN DISCRIMINATOR

Quantum hydrogen discriminator, (physical package (PP) operation is based on RF-cavity electromagnetic field amplification by coherent quantum hydrogen atom transitions. The transition frequency is close to 1420.405 MHz.
The PP schematic diagram is given in Fig. 1
The energy emitted through interrogation loop to the microwave cavity (3) amplifies by hydrogen atoms in the storage bulb and amplified signal is picked up by signal loop. The atom ensemble is then used as a microwave amplifier having a very narrow bandwidth.
The atomic hydrogen is produced from molecular hydrogen by RF dissociation in a discharge bulb (9). For this purpose 120 MHz generator with 4-6 Wt of RF power (10) is used.
The volume of the storage bulb (4) is order of 0.5 dm^3. Its inner wall is coated with an appropriate material (FEP 121) which minimizes the perturbation of the atoms during wall collisions.
The storage bulb is located in a microwave cavity (3), tuned at 1420.405 MHz in a region where the microwave field is almost uniform. Small-size magnetron cavity operates in the TE $_{011}$ mode. With a silver wall, the unloaded quality factor realized in practice is about 8000.
State selection is accomplished in an inhomogeneous magnetic field. This occurs in quadrupole magnet (7).
To eliminate the influence of the external magnetic field and barometric pressure on the stability of the atom emission line and cavity frequencies magnetic shield (2) and vacuum chamber (1) surround the discriminator cavity and the beam path.
The pumping of the continuous flux of hydrogen that comes out of the discharge bulb is performed by a non-evaporable Ti getter (8). This pumping method requires no electrical power and uses much less mass than ion pumps with the same pumping capacity and speed for hydrogen.
The molecules for which the Ti getters are not efficient (nitrogen, oxygen, carbon dioxide and hydro-carbon) are pumping by a small ion pump connected to the hydrogen vacuum enclosure.
In the VCH-1006 model new progressive design of RF cavity has been performed [1] The main differences between VCH-1004 and more old CH1-76 PP models include in the construction of the cavity producing as an assembling of separate simple parts, mechanically connected from each to other. Due to the new design of microwave cavity and magnetic shield system the new level of size/mass parameters was reached.
The comparison of main parameters of VCH-1004 and VCH-1006 is given in the Table 1

Table 1

Model of PP	VCH-1004	VCH-1006
Size/mass parameters		
length	470 mm	440mm
diameter	224 mm	182mm
mass	22 kg	14 kg
Physical parameters		
Cavity quality factor	9 000	8 000
Line quality factor	6-7 E+8	6-7 E+8
Unsaturated power gain	5 dB	4 dB
Spin-exch. broadening	1.2 Hz	1.3 Hz
Geom.+ wall broadening	1.1 Hz	1.1 Hz

One can see that with a very high reduction of mass we did not loose the main physical parameters (unsaturated power gain and line quality factor) that determine the frequency stability of full instrument.

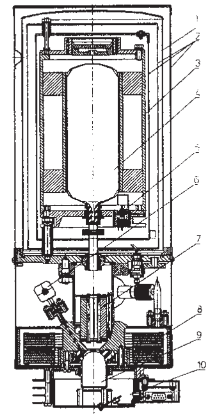

Fig.1 VCH-1006 quantum discriminator

3. ELECTRONIC SYSTEM

The VCH-1006 principle of operation is based on crystal oscillator frequency f_q locking to the discriminator hydrogen atom emission line frequency. The discriminator RF-cavity frequency f_c fluctuations influence on emission line is eliminated by RF-cavity frequency f_c adjustment to the interrogation signal frequency. As the energy level, emitted by hydrogen atoms, is less than sum of loss energy in the discriminator, FM interrogation signal is applied to discriminator RF-cavity to provide spectral line indication and amplitude modulation with F_{MOD} at the output of quantum discriminator.
Electronic system of VCH-1006 is based on the model with interrogation signal method having only one modulation frequency, using both the cavity and crystal oscillator frequency control loops, offered by G. Busca [2]. VCH-1006 block diagram is given on Fig. 2

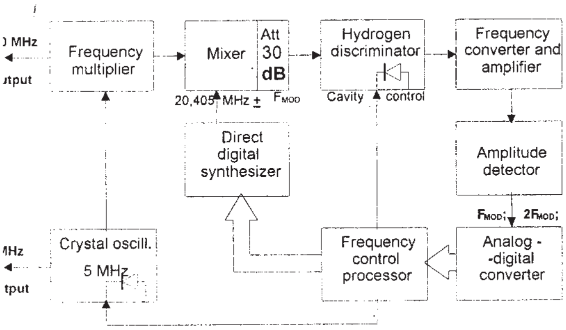

Fig 2. VCH-1006 block diagram

Interrogation signal 1420,40575167 MHz is forming by multiplication of the main crystal oscillator frequency 5 MHz up to 1400 MHz and mixing with the signal tunable direct digital synthesizer having the phase modulation 8,33 kHz and modulation factor near 1.3. Finally, 1420.405 MHz excitation signal is separated directly in discriminator RF-cavity.
Direct digital synthesizer (DDS), based on microcircuit AD9852, combines precise accuracy in setting the nominal frequency of output signals (5 MHz, 100 MHz) and ultra-linear frequency modulation of 20.4057517 MHz signal performing by Frequency Control Processor Fig. 3.

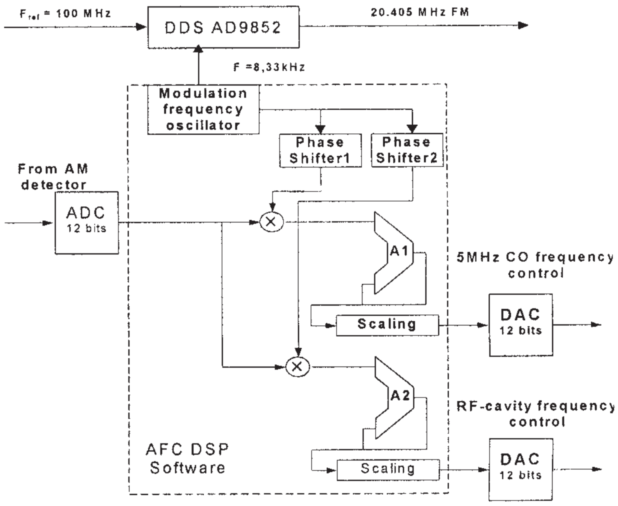

Fig. 3 Block diagram of frequency control processor

Output signal of DDS is preceded by inverse SIN(X)/X filter that precompensates output amplitude variations to achieve flat amplitude response and thereby to exclude stray amplitude modulation with F_{MOD} = 8,33 kHz. The synthesizer is controlled by software executed on a digital signal processor TMS320VC5402.
As a result of interaction the interrogation signal with emission line and maser RF-cavity output discriminator signal contains in its envelope amplitude modulation components with 8,33 kHz proportional to frequency offsets of the (emission line - crystal oscillator) and (crystal oscillator - RF cavity) frequencies. These components are orthogonal and can be easy divided by phase shifters.
Envelope signal from AM-detector passes again to Frequency Control Processor, where its amplification, conversion and detection take place. At first signal is applied to analog-to-digital converter and further to the digital signal processor. To separate the signals and calculate control codes two synchronous detectors are used. Each of synchronous detectors consists of phase shifter, code multiplier, accumulator and scaling shifter. Phase shifters 1 and 2 allow choosing correspond phase of modulating frequency oscillator (MFO) code. Accumulator A1 and A2 integrate the error signal codes and scaling shifters set desired time constant. Control signals for crystal oscillator and maser Rfcavity perform by two 12 bits digital analog converter. The influence of the second harmonic of F_{MOD} eliminated by linearity of digital synchronous detection process.

4. EXPERIMENTAL RESULTS

Results of experimental investigation of the first sample VCH-1006 passive H-maser frequency and time standard are given in Table 2

Table 2

Relative frequency reproducibility	1×10^{-13}	Phase noise (dB/Hz) (at the 5 MHz) 10 Hz 100 Hz 1000 Hz	-130 -140 -150
Frequency corrector : Resolution retuning range	 1×10^{-15} 1×10^{-10}	Magnetic sensitiveness, (1/Oersted)	2×10^{-14}
Frequency stability 1 sec (Allan variance): 10 sec 100 sec 3600 sec 1 day	6×10^{-13} 2×10^{-13} 5×10^{-14} 2×10^{-14} 5×10^{-15}	Temperature coefficient, (1/ ° C) Operating temperature range, (° C)	5×10^{-15} +5 ÷ +40
Power: 220 V 50 Hz AC 48 ± 10 or (24 $\pm^{6}_{3}$) V DC	60 W	Dimensions (mm) Weight (kg)	470×200×550 30

7. REFERENCES

1. A.Beliaev, I Pavlenko "Quantum hydrogen discriminator" Patent RF for the useful model No. 18118 from 28.11.2000

2. G. Busca, H. Branderberger "Passive H-maser" Proc. 33-rd Ann. Freq. Cont. Symp., 1979, p.563-568