MODERN STATE OF DEVELOPMENT AND MANUFACTURE OF RUBIDIUM FREQUENCY STANDARDS AND REFERENCE OSCILLATORS

V. Dubkov, V. Gritsenko, A. Ogarkov, J. Sapohznikov, S. Selivanov, A. Sheronov,
Treskov, C. Green
IEM KVARZ

At present time a great demand for Rb time and frequency standards (especially for Rb reference oscillators) was formed in industry of highly developed countries. The development of reference oscillators logically stems from frequency standard development.

The demand for Rb reference oscillators and frequency standards is dictated by the fact, that modern technical requirements for navigation, communication equipment and synchronization do not allow to use in this equipment traditional crystal oscillators as reference oscillators due to their not sufficiently high metrological characteristics (frequency drift, frequency reproducibility, frequency stability).

Rb frequency standards and reference oscillators are alternatives to crystal oscillators. They by 10-100 times surpass crystal oscillators in metrological characteristics and approach them closely by weight and power consumption.

IEM KVARZ for more than 40 years has been developing and manufacturing Rb frequency standards and Rb reference oscillators. For the time elapsed we have formed a unique technological base and have trained a highly professional personnel. All this allows to solve any tasks in the given branch of instrument making industry.

At present IEM KVARZ has developed and manufactured three basic models of Rb frequency standards and Rb reference oscillators. They are: the CH1-81 Rb Frequency Standard for operation in severe operating conditions, the R1050 commercial Reference Oscillator and the R300 commercial Reference Oscillator.

On their base we have we have developed the following options: CH1-81/1, CH1-81/3, CH1-81/5, CH1-81/2, CH1-81/4, R1050A, R1050B, R1050C, VM2201, R300/1, R300/2, R450/1, R450/2. Their specifications are given in the Table 1. The CH1-81/1, CH1-81/3 differ from the CH1-81 by a standard case and CH1-81/4, CH1-81/5 differ from CH1-81/2, CH1-81/3 by the time scale former with 1s pulse repetition rate.

The CH1-81/2,3 is composed of the CH1-81/2,3 Frequency Standard and the CHK7-51 Frequency Comparator and is essentially a measuring Time and Frequency Standard. It is designed to form 1 and 10MHz signal from a 5 MHz reference signal, to measure relative frequency deviation of 5 and 10MHz measured signal in relation to a 5MHz reference signal, to measure systematic drift, RMS deviation and variation. The instrument also measures pulse time shift of an external or an auxiliary time scale in relation to me main scale performs measurement result statistical processing and displays them on indicator. It also provides formation of the pulses of the main and auxiliary (delayed) time scales with 1s pulse repetition rate and displays current time in seconds, minutes, and hours on the indicator.

The frequency standard and time scale former provide specification under the following condition:

- Operating temperature range: -40 ÷ +55 ^{o}C (0 ÷ +50 ^{o}C for the CHK7-51 Comparator);
- Exposure to condensed precipitations (hoar-frost, dew);
- Transportation with exposure to shock with acceleration 10 and 15g. During transportation clock daily rate variation per hour is not more than $\pm$0,05μs.

Table 1.1 Rb Frequency Standards and Rb Reference Oscillators specifications

Characteristic	**Instrument model**	
	CH1-81	CH1-81/1
Systematic frequency drift per 24 h	$\leq 1.0 \cdot 10^{-12}$	$\leq 3.0 \cdot 10^{-12}$
Frequency stability 1s 10s 100s	 $1.0 \cdot 10^{-11}$ $5.0 \cdot 10^{-12}$ $3.0 \cdot 10^{-12}$	 $1.0 \cdot 10^{-11}$ $5.0 \cdot 10^{-12}$ $3.0 \cdot 10^{-12}$
Phase noise, dB/Hz, 100Hz 1 kHz 10 kHz	 130 140 150	 130 140 150
Operating temperature range, C^{o}	-40 ÷ +55	-40 ÷ +55
Frequency shift in temperature range	$1.2 \cdot 10^{-10}$	$1.2 \cdot 10^{-10}$
Volume, dm^{3}	4.75	4.75
Weight, kg	3.5	3.5
Power,V	27^{+3}_{-5}	27^{+3}_{-5}

Table 1.2 Rb Frequency Standards and Rb Reference Oscillators specifications

Characteristic	Instrument model		
	R1050A	R1050B	R1050C
Systematic frequency drift per 24 h	$4.0\cdot10^{-13}$	$1.3\cdot10^{-12}$	$1.3\cdot10^{-12}$
Frequency stability 1s 10s 100s	 $1.0\cdot10^{-11}$ $3.0\cdot10^{-12}$ $1.0\cdot10^{-12}$	 $1.5\cdot10^{-11}$ $5.0\cdot10^{-12}$ $2.0\cdot10^{-12}$	 $1.5\cdot10^{-11}$ $5.0\cdot10^{-12}$ $2.0\cdot10^{-12}$
Phase noise, dB/Hz 100Hz 1 kHz 10 kHz	 130 140 150	 130 140 150	 140 150 155
Operating temperature range, C^o	-40 ÷ +55	-40 ÷ +55	-40 ÷ +55
Frequency shift in temperature range	$2.0\cdot10^{-10}$	$2.0\cdot10^{-10}$	$2.0\cdot10^{-10}$
Warm up time to $1\cdot10^{-9}$, minutes	7	7	7
Volume, dm^3	1.1	1.1	1.1
Weight, kg	1.5	1.5	1.5
Power,V	$27^{+\circ}_{-}$	$27^{+\circ}_{-}$	$27^{+\circ}_{-}$

Table 1.3 Rb Frequency Standards and Rb Reference Oscillators specifications

Characteristic	Instrument model			
	R300/1	R300/2	R450/1	R450/2
Systematic frequency drift per 24h	$1.3\cdot10^{-12}$	$3.3\cdot10^{-12}$	$1.3\cdot10^{-12}$	$3.3\cdot10^{-12}$
Frequency stability 1s 10s 100s	 $3.0\cdot10^{-11}$ $1.0\cdot10^{-11}$ $3.0\cdot10^{-12}$	 $8.0\cdot10^{-11}$ $3.0\cdot10^{-11}$ $1.0\cdot10^{-12}$	 $3.0\cdot10^{-11}$ $1.0\cdot10^{-11}$ $3.0\cdot10^{-12}$	 $8.0\cdot10^{-11}$ $1.0\cdot10^{-11}$ $3.0\cdot10^{-12}$
Phase noise, dB/Hz, 100Hz 1 kHz 10 kHz	130 140 150	130 140 150	130 140 150	130 140 150
Operating temperature range, C^o	-10 ÷ +55			
Frequency shift in temperature range	$3.0\cdot10^{-10}$	$5.0\cdot10^{-10}$	$3.0\cdot10^{-10}$	$5.0\cdot10^{-10}$
Warm up time to $10\cdot10^{-9}$, minutes	5	5	5	5
Volume, dm^3	0.33	0.33	0.45	0.45
Weight, kg	0.43	0,43	0.47	0.47
Power,V	$27^{+\circ}_{-}$	$27^{+\circ}_{-}$	$27^{+\circ}_{-}$	$27^{+\circ}_{-}$

On the base of R1050 Reference oscillator we have developed the VM2201 Rb Time and Frequency Standard. It is a VXIbus double size module weighting 3,5 kg. When using it as a reference oscillator together with the VM0403 Frequency Comparator we can test quartz crystal oscillators with low metrological characteristics.

All the instruments manufactured by IEM KVARZ are covered by patents. We have a high efficient production equipment capable to provide shipments of any volume. The most interesting pieces of equipment are:

- Vacuum optical pumping source;
- The working substance of the absorption cell and the optical pumping source at time is an alloy of alkali metal isotope Rb^{87} with potassium (K) and at other times - quantum discriminator (Rb^{87} + Rb^{85} +K) without an optical filter.

In sight of further developments the main effort must direct our attention on development of two types of quantum discriminators – miniature and high-stable.

The prime objective of miniature quantum discriminator development is the construction of a reference oscillator with 18-20 mm case height. This provides even greater advantages over quartz crystal oscillator – to develop a single slot Rb time and frequency standard for a VXIbus equipment. Essentially we have fulfilled the task set. We have developed and manufactured the discriminator mock-up with a microwave part of non-cavity type. We have obtained the signal-to-noise ratio sufficient to realize $(1{\div}3)\cdot10^{-11}\sqrt{\tau}$ frequency stability. The quantum discriminator volume is 15 cm^3 at 20 mm height.

The prime objective of high stable quantum discriminator development is the construction of a Rb frequency standard which at sufficiently low systematic frequency drift ($(1{\div}3)\cdot10^{-13}$ per 24 hors) will have guaranteed short-term stability of $(1{\div}2)\cdot10^{-13}$ per second. Such a frequency standard tuned in accordance with precise time signals (time scale) of satellite navigation systems (GLONASS/GPS), taking into account its price in a majority of applications will compete with passive H-Masers and cesium frequency standards.

Nowadays we have manufactured two mock-ups of a high-stable discriminator which together with a radio equipment produces the following short-term stability (Table 2).

Table 2

Mock up N	Time		
	1s	10s	100s
1	$1.42\cdot10^{-12}$	$4.08\cdot10^{-13}$	$2.11\cdot10^{-13}$
2	$1.42\cdot10^{-12}$	$4.54\cdot10^{-13}$	$1.07\cdot10^{-13}$

In an automatic frequency control circuitry we have used quartz crystal oscillator with a frequency stability of $(4{\div}5)\cdot10^{-12}$ per second.