Lowest Flicker-Frequency Floor Measured on BVA Oscillators

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***Abstract*—In this paper we will present the results of the time-domain measurement of short-term frequency stability on seven ultra-stable 5 MHz Oscillloquartz 8600 and 8607 BVA oscillators. The measurement took place in the Institute of Photonics and Electronics (IPE) in July 2008 and was a continuation of the previous stability measurements of BVA oscillators reported in [1].**

I. Introduction

The state-of-the-art quartz oscillators based on the BVA technique are extremely stable frequency sources in the short term [2]. Their limiting noise has a character of flicker frequency modulation with the noise floor of less than $4\text{x}10^{-14}$ in terms of Allan deviation, $\sigma_y(\tau)$, of average fractional frequency. Thus at averaging intervals of a few seconds, the BVA quartz oscillators achieve better stability than the best active hydrogen masers.

To measure the short-term frequency stability of these precision oscillators, a highly sensitive measurement system is needed with background stability less than 10^{-14} at 1 s. Unfortunately the commercially available instruments do not provide such performance and therefore dedicated laboratory system has to be built to satisfy this requirement.

At the Time and Frequency Department we have developed such a system based on the classical dual-mixer time-difference multiplication (DMTDM) [3], [4], [5], [6], [7], [8], [9] which we have optimized to achieve the minimum background noise at an averaging interval of 1 s [10], [11]. The first experimental version appeared in 2003 and since then much improvement has been made [10], [11].

The capability of our system has recently been verified in repeated measurements on the best ever produced BVA quartz oscillators [1]. The measurements have been carried out within the #847 EURAMET Project in collaboration with *Franche Comté Electronique Mécanique Thermique et Optique - Sciences et Technologies*, Besançon, France, and with the producer of the oscillators – Oscilloquartz (OSA) S.A., Neuchâtel, Switzerland. The two partners provided the 5 MHz 8607 OSA oscillators which we measured along with our 8600 two OSA BVA units.

II. Measurement Basics

The measured quantity is the variations in the phase-time difference between two quasi-synchronous sine-wave signals at nearly equal frequency. The measurement sensitivity is enhanced using the dual-mixer time-difference multiplication (DMTDM).

The method is based on dual mixing the two compared signals at frequency ν with a signal at frequency $\nu \pm \nu_B$ from a common oscillator (CO) to provide two beat-note signals at ν_B. The multiplication factor is thus $M = \nu/\nu_B$.

A time-interval counter then periodically measures the time interval, x_k, between two adjacent zero-crossings of the compared beat-note signals.

The measurement result is the frequency stability estimated from the sequence $\{x_k\}$ in terms of Allan deviation $\sigma_y(\tau)$ as a function of the averaging time interval τ [12], [13].

Since these ultra-stable oscillators have comparable short-term stability none of them can be taken as reference as it is common in metrology. Thus what we actually obtain from the comparison is the pair stability rather than individual stability

$$\sigma^2_{AB}(\tau) = \sigma^2_A(\tau) + \sigma^2_B(\tau). \quad (1)$$

To decompose the pair stabilities into individual stabilities we need to measure at least three oscillators and then employ the three-cornered-hat method under the assumption of uncorrelated signals.

III. Phase-Time Comparator

A dedicated laboratory phase-time comparator, IPE3, based on DMTDM technique has been used in our comparisons. The common signal of the comparator is provided from a 5 MHz Milliren MTI260-504A quartz

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oscillator. Its output frequency is offset by 5 Hz and the output level is low-noise amplified to +11 dBm.

The comparator makes use of Stanford Research SR620 time interval counter. The measured data is collected by PC and further processed using the Stable32 software [14].

The equivalent noise bandwidth of the IPE3 system is 26 Hz and it can be optionally switched to 260 Hz.

Figure 1. shows the results of the system background stability tests by using two +4 dBm signals power split from one BVA reference oscillator.

Given the extremely high sensitivity of the measurement, we have experienced great difficulties in reducing the electromagnetic interference and other environmental effects that occur irregularly and make the disturbing process non-stationary in the short-term sense.

To our knowledge the background stability of 5.6×10^{-15} at 1 s in 26 Hz bandwidth is the best ever achieved in a time-domain measurement at 5 MHz. Thus our DMTDM is a unique system that allows to measure the best BVA oscillators. It may also be considered as a benchmark for the future systems that will employ immediate analog-to-digital conversion of the measured signal.

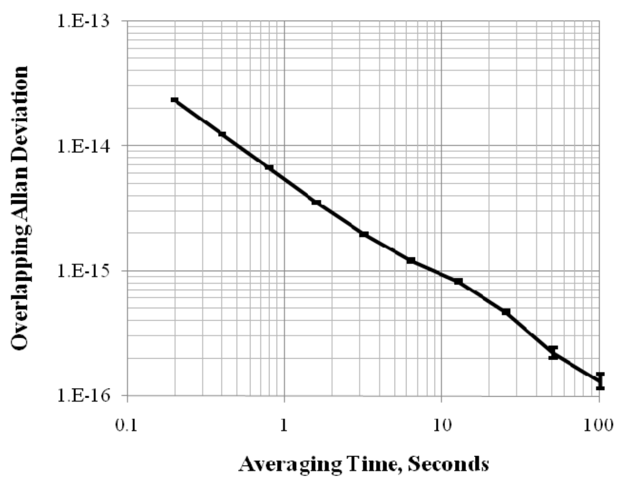

Figure 1. Background stability of IPE3 system.

IV. COMPARED OSCILLATORS

During the last measurement campaign in July 2008 we had at our disposal seven BVA oscillators listed in TABLE I.

TABLE I. COMPARED OSCILLATORS

Type	S/N	Possessed By	Name
8600	291	IPE	A
8600	315	IPE	B
8607	199	FEMTO-ST	D
8607	543	OSA	E
8607	567	OSA	F
8607	691	OSA	G
8607	692	OSA	H

Each oscillator showed the flicker frequency modulation floor of less than 1×10^{-13}.

Before the measurement all of the oscillators were mounted into extra cases each with an arrangement for fine tuning with a relative frequency resolution of 1×10^{-12}. These extra cases also ensured additional shielding for the oscillators. The fine tuning allowed us to maintain the compared signals in quasi-synchronism to within 1 ns which is needed to reject the noise originating from the DMTDM common oscillator.

Each measurement session lasted at least 4000 s which, given the basic sampling interval of 200 ms, provided robust enough statistics for stability analysis. We have performed about hundred of these measurement sessions in different periods of day and week with all possible combinations of oscillator pairs.

To reject disturbances from power line the phase-time comparators and all of the oscillators were battery powered during all measurements. In addition the time interval counter and the computer that collected the data were powered through an isolation transformer.

V. MEASUREMENT RESULTS

Seven oscillators make 21 possible oscillator pairs from which we focused mainly at three best units E, F and H.

The oscillator pair stabilities $\sigma_{EF}(\tau)_i$, $\sigma_{EH}(\tau)_i$ and $\sigma_{FH}(\tau)_i$ are shown in Figure 2 to Figure 4. Here the confidence intervals are hidden for sake of clarity. The corresponding number of performed comparisons is 11, 14 and 16, respectively.

The Stable32 analysis program has been used for calculation of frequency stability of each oscillator pair.

The outliers and frequency drift were removed from the measured data prior to all calculations.

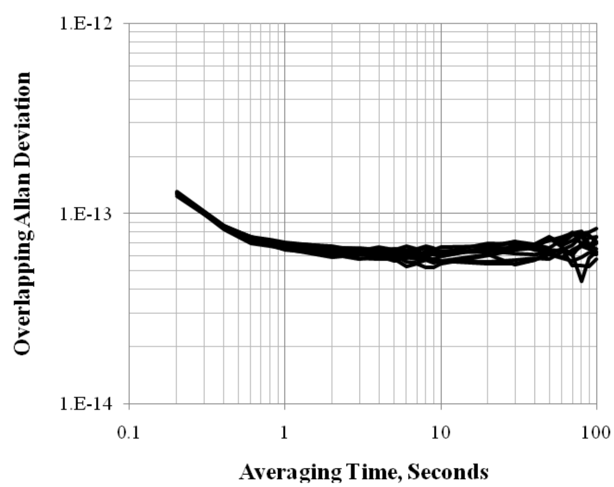

Figure 2. Frequency Stability of E-F Oscillator Pair.

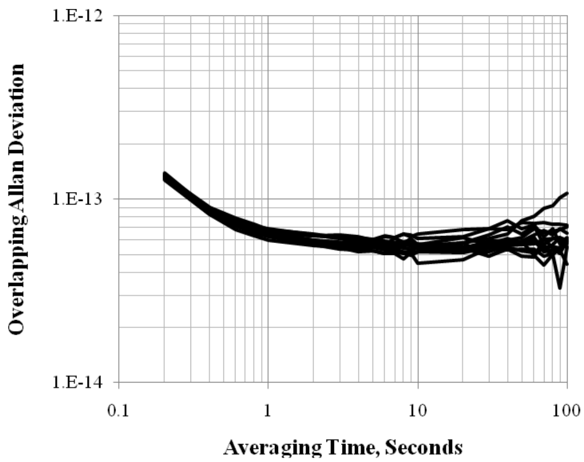

Figure 3. Frequency Stability of E-H Oscillator Pair.

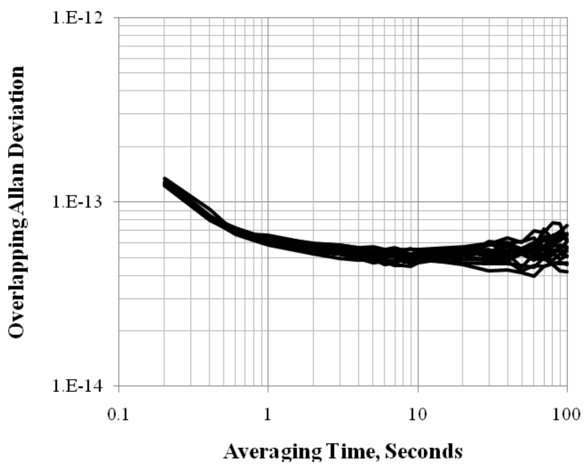

Figure 4. Frequency Stability of E-H Oscillator Pair.

By employing the over-determined three-cornered-hat method, we have obtained the results depicted in Figure 5.

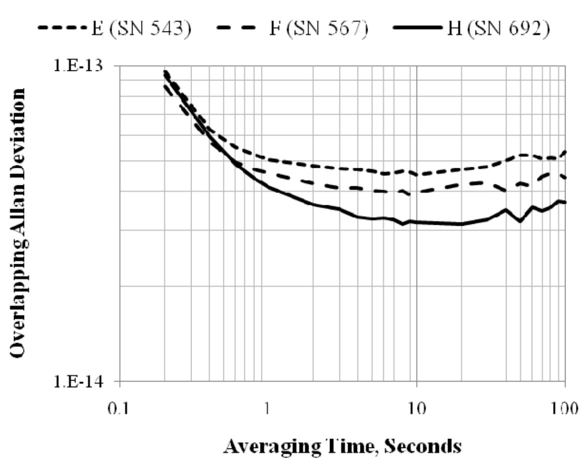

Figure 5. Frequency stability of the reference oscillators of the OSA.

The corresponding flicker-frequency floors are 3.2×10^{-14}, 4.0×10^{-14} and 4.5×10^{-14}, respectively, in terms of Allan deviation for averaging interval of 5 s.

VI. CONCLUSIONS

In measuring these ultra-stable oscillators it is useful to introduce a model of the inherent stability which is the one obtained with a near-ideal measurement system in non-interfering and stable environment (i.e. with no external electromagnetic interference, stable temperature, no vibrations etc.). Given the low background noise of our DMTDM system and stable environmental conditions in the laboratory, we can assume that our measurement approximates this case. It follows that the stability shown in Figure 5. represents the oscillator noise limits and its performance potential in a given bandwidth. The user, therefore, must consider this result in terms of the oscillator's best capability. Consequently, if he wants to make full use of this capability he must operate the oscillator in "near-ideal" conditions concerning both the application and the environment.

The FFM floor of 3.2×10^{-14} in terms of Allan deviation for averaging interval of few seconds obtained for the H (SN 692) unit is to our knowledge the best value ever reported on a BVA oscillator.

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