Resonator frequency stability contribution to the performance of ultrastable oscillators before and after integration

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ABSTRACT: The aim of this article is to present the performances of the instruments developed for the measurement of 5 MHz ultra-stable resonators, before and after being integrated in an oscillator. The chosen resonator has an estimated stability of several 10^{-14}. Intrinsic noise floor of these benches are about 7 to 9.5×10^{-15}.

INTRODUCTION:

The idea of determining noise of oscillators was mainly guided by industrials concerned with measuring the potentiality of each batch of resonators in order to optimize fabrication cost of ultra-stable oscillators. Indeed, integration of a more or less good resonator could penalize the final cost. It is important to have a tool to sort out the best resonators showing their capabilities to be integrated into the best oscillators. Besides this challenge, there is scientific interest in fully characterizing noise and stability of oscillators by understanding the contributions of both the resonators and the electronics. The phase noise measurement bench of the resonators is presented in the following part of this letter. Performances on oscillators in terms of frequency stability are presented in the latter part.

MEASURING A PAIR OF RESONATORS:

The noise of the resonators to be integrated into Boitiers à Vieillissement Amélioré (BVA) oscillators is measured on a bench developed for 5 MHz resonators [1-6]. The main principle of this bench (shown in Fig. 1 and in Fig. 2) is to reject the split signal delivered by a 5 MHz source into two arms.

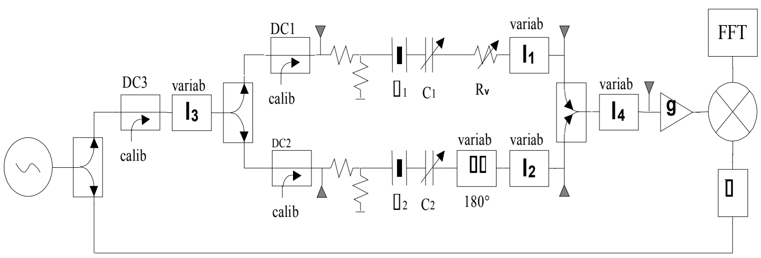

Fig. 1. Principle of the bench

One is in quadrature and pumps the Local Oscillator (LO) input of the mixer. The other is separated in two other arms, each one owning a quasi-similar resonator. Tuning capacitors and attenuators permit the adjustment of frequencies and loading quality factors. These two parallel arms are shifted by 180° in order to adjust suppression of the carrier. These two signals are then recombined, and the lateral bandwidths are amplified to the sufficient Radio Frequency (RF) input of the mixer, pumped by the reference signal in quadrature. Then, a Fast Fourier Transform (FFT) analyzer coupled to a Personal Computer (PC) allows us to obtain the spectral density of phase noise spectrum. Frequency of the resonators is temperature sensitive. It is important to be close to an inversion point where temperature has a minimal influence on the frequency. Hence, resonators to be measured are placed into appropriate thermostats [7] shown in Fig. 3 Resonator number 31 is the one we are concerned with studying. Its temperature of inversion is 79.8°C. Thermostats are especially developed by Oscilloquartz for this kind of measure. They are very similar to the final packaging of oscillators in order to show, as closely as possible, the eventual working conditions of future oscillators.

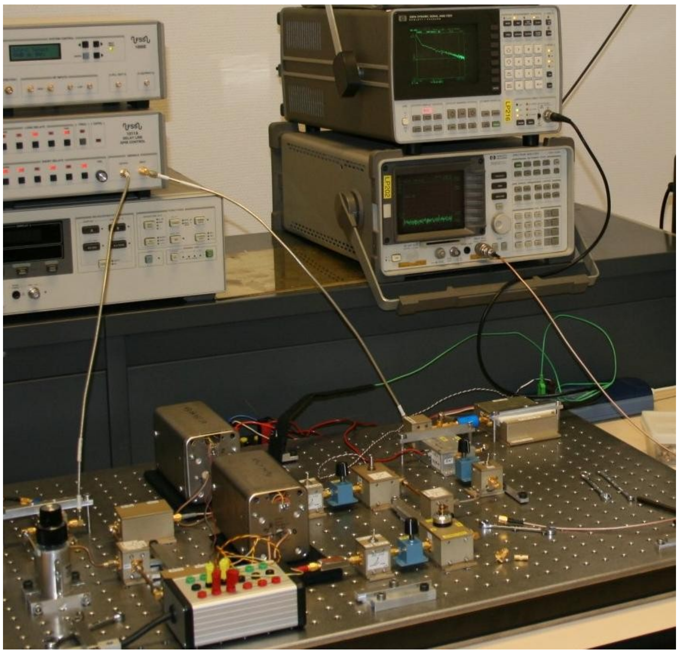

Fig. 2. Picture of the bench

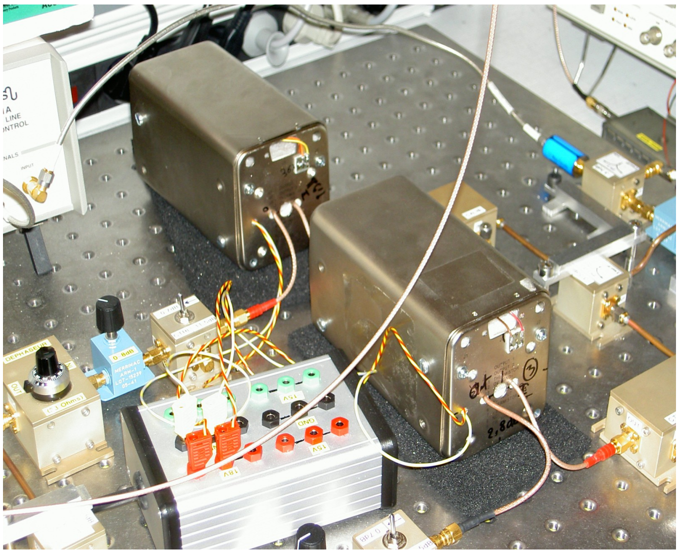

Fig. 3. Photography of thermostats.

For Fourier frequencies $f < f_L$, where f_L is the cut-off frequency, the resonator filters its own frequency fluctuations leading to a $1/f^3$ slope on the spectral density of phase noise $S_\Phi(f)$. Frequency cut-off of the resonator which is a low pass filter is $f_L = \nu_0/Q_L$ where ν_0 and Q_L are respectively the carrier frequency - which here is equal to 5 MHz - and the loaded quality factor. We can then write that $S_y(f) = (f_L/\nu_0)^2.S_{\Phi m}(f)$. From $\sigma_y(\tau)=\sqrt{(2.Ln2h^{-1})}$, with $h^{-1}= f_L^2/\nu_0^2.S_\Phi(1Hz)$, we deduce that the frequency stability is at 1 s from the carrier. For this resonator number 31, $Q_L = 2.74x10^6$. It has been measured with other resonators of the same batch. Figure 4 presents the curve obtained with the measurements of resonator number 31, along with another from the same batch. Input power of each resonator is 60 µW. Spectral density of phase noise is $S_\Phi(1Hz)$ = -133 dB.rad²/Hz. Cut-off frequency is 1,61 Hz.

The loaded quality factor is then $Q_L = 1.55x10^6$.

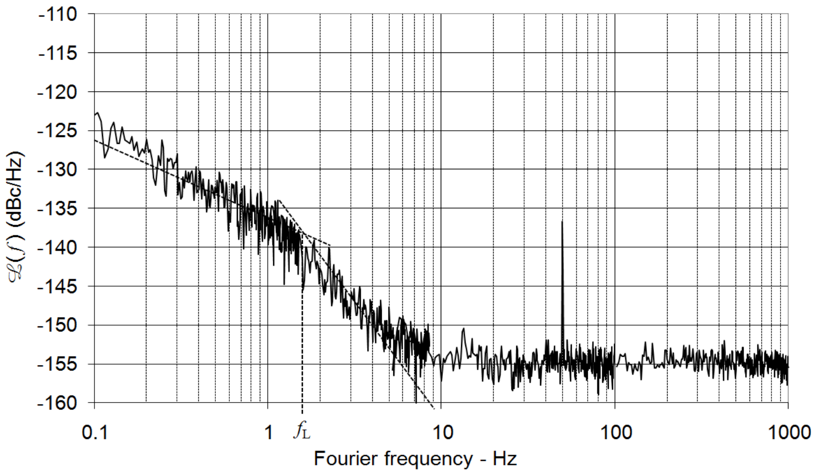

Fig. 4. Phase noise spectrum

We can deduce that the frequency stability of the measured resonator pair is $8.5x10^{-14} \pm 1.5x10^{-14}$ at 1 s for the 5 MHz carrier. Noise floor of the bench is $9.5x10^{-15}$. If two resonators are exactly the same, frequency stability of each one could be obtained by dividing the obtained frequency stability of the pair by the square root of two. However if one of them presents worse stability, it will limit the obtained value of the frequency stability. So, the measured value is a upper value. Considering that the resonators have the same contribution, frequency stability of resonator number 31 is $6.0x10^{-14} \pm 1.5x10^{-14}$. It gives an indication for sorting out the best resonators. Frequency stability of the oscillator is determined after packaging the resonator with electronics.

FREQUENCY STABILITY MEASUREMENTS ON OSCILLATORS:

The main principle of the bench (shown on Fig. 5) is based on Dual Mixer Time Difference Multiplication (DMTDM) with a beat frequency of 5 Hz. Each measure gives 10,000 samples. They are separated by a basic 200 ms integration time. When tested with the rejection of one BVA Oscillator, it is possible to deduce a flicker phase of $7x10^{-15}$ at 1 s. It can be negligible in the region where flicker floor is performed measuring between 1 and 100 s.

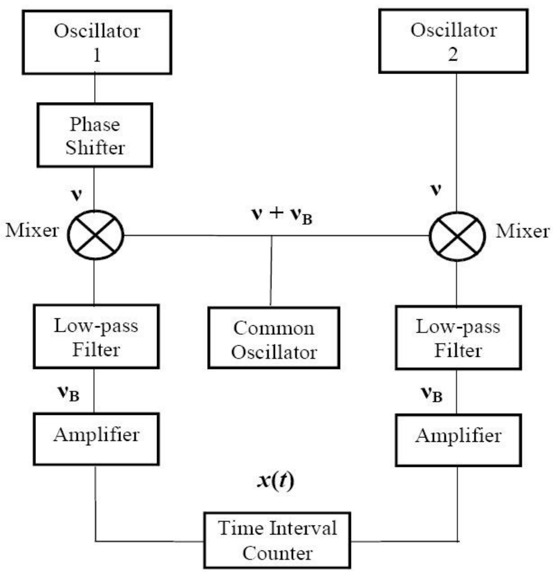

Fig. 5. Principle of the DMTDM bench

The resonator number 31 is integrated into an oscillator and its number becomes 691. It is measured with other BVA oscillators. The best of them present flicker floor as low as 3.2×10^{-14} [8] deduced by triangulation on several measures performed on different pairs of resonators [9-10].

The curve represented in Fig. 6 shows a flicker floor at 7.5×10^{-14} for integration times between 10 s and 100 s. D, G and J represent measurements performed respectively 24h, 1 week and 2 weeks after they are brought. Even if those oscillators were carried under batteries during transport, each short disconnection can have an effect on the value of the stability. At 1 s, frequency stability of the pair can be estimated to be 9.5×10^{-14}. The two oscillators present similar performances. This is why, in a first approximation, their contribution to the measured noise can be considered as equal. An estimative value of the stability of one oscillator can then be 6.7×10^{-14} at 1 s, with a FFM floor at 5.5×10^{-14} between 20 s and 100 s. We can attribute these values with an uncertainty equal to $\pm 3 \times 10^{-15}$.

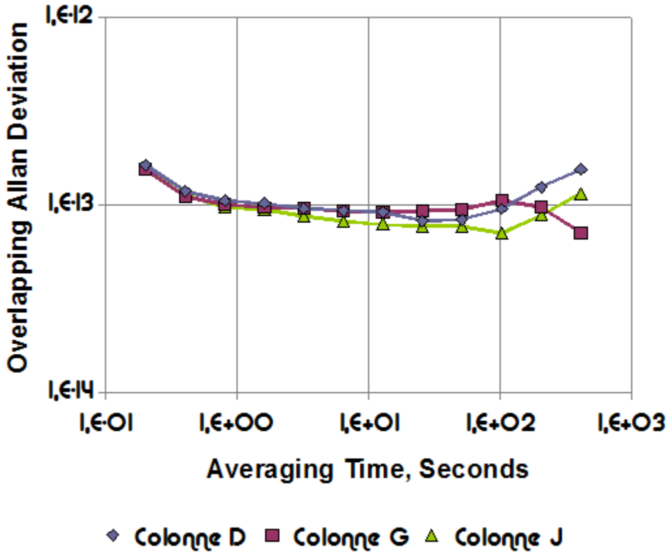

Fig. 6. Frequency stability of oscillators pairs

CONCLUSION:

Making the hypothesis that two resonators make an equal contribution to the noise, measurements on the traceable resonator show frequency stability is $6.0 \times 10^{-14} \pm 1.5 \times 10^{-14}$. The frequency stability of the oscillator is $6.7 \times 10^{-14} \pm 3 \times 10^{-15}$ at 1 s and shows that there is almost no influence of electronics. These instruments are adequate for the measure of state-of-the-art resonators and oscillators at 5 MHz [11-12].

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