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Technical note

Distributed amplified ultra-stable signal quartz oscillator based

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ABSTRACT

The aim of this communication is to present the performances of 5 MHz distributed ultra-stable system, based on ultra-stable Boitiers à Vieillissement Amélioré (BVA) oscillator. We demonstrated flicker frequency modulation (FFM) floor better than $4.5 \times 10^{-14} \pm 2.5 \times 10^{-15}$ at 12 s with an intrinsic noise floor about 6×10^{-15} at 1 s with a $\tau^{-1/2}$ time integration dependence slope.

1. Introduction

For spectral density of phase noise and short term stability measurements, stable reference sources are needed. With recent progress in ultra-stable radio frequency sources [1–3], noise of distribution amplifiers must be the weakest possible to keep the noise floor the lowest. Thus we achieve a high performance distribution amplifier. For a 1 s integration time, it must be better than 2.5×10^{-14} [1]. A distribution amplifier is realized and its design and performances are presented in the following part of this letter. An ultra-stable Boitiers à Vieillissement Amélioré (BVA) oscillator is then integrated and is fully characterized to validate the system at its highest level. Performances as lower as 4.5×10^{-14} are found for the flicker frequency modulation (FFM) floor on oscillator and distributed signal in terms of frequency stability. These results are presented in the latter part.

2. Design and characterization of the system

The design is optimized for low noise signals to be delivered at 5 and 10 MHz to be integrated with a Boitier à Vieillissement Amélioré (BVA) reference oscillator. A picture of the distribution amplifier system (DAS) is shown in Fig. 1, and the DAS is schematically represented in Fig. 2. A good isolation is expected and it is necessary that output power keep a good flatness for both 5 and 10 MHz outputs. Our purpose consists in optimizing the performances of this device to allow integration of the best available commercial BVA oscillators. The quartz resonator is there mechanically stabilized by non-adherent electrodes. It presents a double copper oven structure that considerably helps for thermal isolation of the quartz resonator, especially because it is compacted in a dewar flask. The first oven is mechanically hold by a rigid composite material. The internal oven control card is placed in the second copper oven. The external card is placed inside the dewar flask. Moreover this system deliver two 5 MHz and two 10 MHz outputs. An amplifier and a ×2 multiplier based on an

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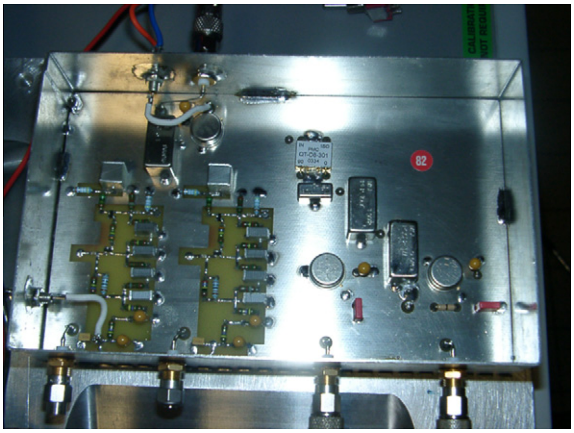

Fig. 1. Picture of the distribution amplifier board.

hybrid junction are placed on one arm to deliver the 10 MHz output signals. The amplifier stage is significantly improved thanks to the multiplication by two, that is the doubling. It allows an optimal performance in power, combined with an excellent noise factor. It is achieved by using the rectifier effect of a diode bridge. To reject harmonics, signal is filtered before the input and after multiplication and amplification. Spurious peaks are especially filtered by low pass filters for 20 and 30 MHz. For a +7 dBm 5 MHz input signal, we then respectively achieve −41, −76 and −91 dBc for 10, 20 and 30 MHz at the 5 MHz distributed output.

A set of two distribution amplifiers is realized for characterization of the floor of both of these boards. We deduce their performances by analyzing the results of S_Φ, the spectral density of phase noise measurement. The measurement setup is given in Fig. 3. $S_\Phi(1\text{ Hz}) = -141.4\text{ dB rad}^2/\text{Hz}$ at 5 MHz and $-141\text{ dB rad}^2/\text{Hz}$ at 10 MHz with a $1/f$ slope. It is obtained by measuring the phase noise of two similar outputs of the distribution amplified quartz based system. We deduce the value considering that the two output have identical contribution to the noise. For a $1/f$ slope in the spectral domain, we use the following relation referenced (1) to deduce $\sigma_y(\tau)$ versus the spectral density of phase noise [4]:

$$\sigma_y^2(\tau) = [h_1/(4\pi^2 \cdot \tau^2)] \cdot [9/2 + 3\text{Ln}(2\pi F_h \tau) - \text{Ln}2] \quad (1)$$

where h_1 is the coefficient of the slope at 1 Hz, τ the integration time, F_h cutoff frequency of the noise.

This equation allows us to estimate the frequency stability in terms of Allan variance, $\sigma_y^2(\tau) = 1.39 \times 10^{-14}$ at 1 s for the 5 MHz signal, and $\sigma_y^2(\tau) = 7.29 \times 10^{-15}$ at 1 s for 10 MHz. These results are very close to the state-of-the-art results

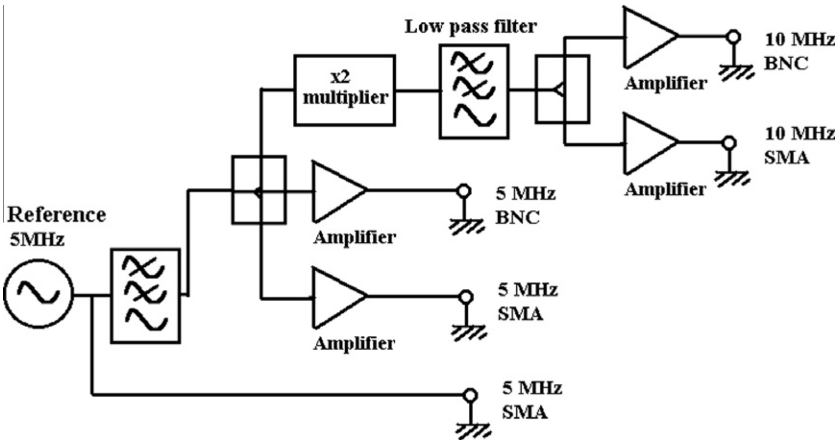

Fig. 2. Diagram of the distribution amplifier circuit.

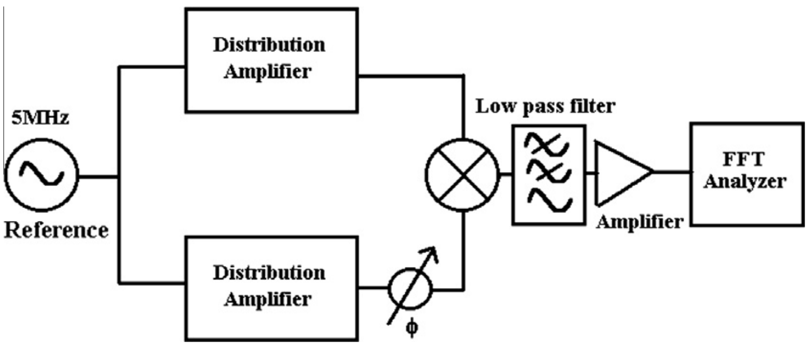

Fig. 3. Phase noise measurement setup.

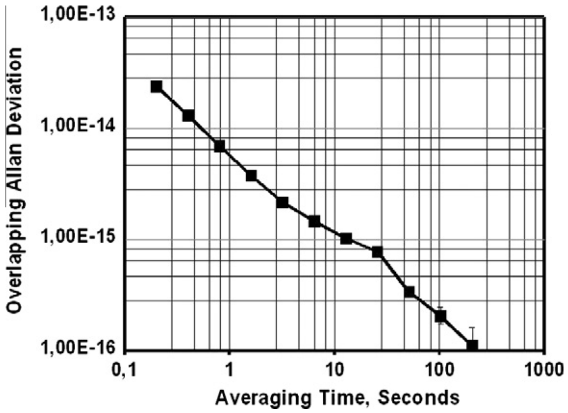

Fig. 4. Bench limit.

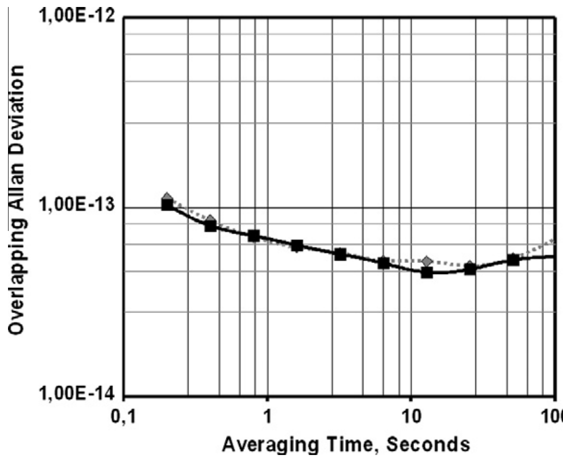

Fig. 5. Frequency stability measurements on DAS 5 MHz output versus BVA reference. Rhombus: BVA reference versus BVA #199 direct output, Square: BVA reference versus BVA #199 distributed output.

[5–8] and are low enough for distribution of the best BVA oscillators [1].

3. Frequency stability measurements on system integrated oscillator

For determining the performance of the system in terms of short term frequency stability, main principle is based on Dual Mixer Time Difference Multiplication (DMTDM) [8–11] with a beat frequency of 5 Hz. Each measure gives 10,000 samples [2,3] and they are separated by a basic 200 ms integration time. For evaluating the limit of the bench, we test the rejection of one BVA oscillator, to be able to deduce a flicker phase of 6×10^{-15} at 1 s with a $\tau^{-1/2}$ slope. Fig. 4 represents the limit of the measuring system. It is clearly negligible in the 1–100 s region where flicker floor is measured. The direct output of the selected BVA oscillator number #199 is first measured on the DMTDM bench and then integrated with the distribution amplifier as described above. It is measured with in comparison with the best reference oscillator previously demonstrated to present a 2.5×10^{-14} FFM floor [1], noted 'BVA reference' on the legend of Fig. 3. It has to be underlined that thanks to the fact we have measured the BVA #199 previously comparatively to the best BVA, we can be sure of our results with the present experiment. The curve represented in Fig. 5 shows a FFM floor at $4.5 \times 10^{-14} \pm 2.5 \times 10^{-15}$ for a 12 s integration time at the distributed output of the integrated system. This result is mainly due to the contribution of the intrinsic noise floor of the 5 MHz BVA #199 oscillator set as the reference distributed through the DAS. It has to be underlined that those oscillators and DAS were carried under batteries during transport, as each short disconnection can have an effect on the value of the stability at such low levels.

4. Conclusion

Thanks to the use of the best reference signal for evaluate the performance of the designed and realized DAS, measurements clearly show that the developed DAS is accurate for the new generation of 5 MHz state-of-the-art BVA oscillators appearing in the recent period. To our knowledge, it is the first time that such performances have been measured for a DAS in time domain.

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