Low phase noise compact optical delay line optoelectronic oscillator

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ABSTRACT

In this paper, the uncertainty on the phase noise measured for a low phase noise compact optical delay line optoelectronic oscillator is evaluated as ±2 dB at 2 σ.

KEYWORDS

Optoelectronic oscillator; microwave signal; uncertainty; uncertainty analysis; error; noise.

1. INTRODUCTION

There are several examples of works on Optoelectronic oscillators in the literature [1 – 3]. A compact optical delay line optoelectronic oscillator is designed to fit in a volume of less than 1 litre. It consists of a 1.55 µm wavelength laser, a modulator, a resonant element or an optical fiber acting as a delay line, a photodetector, a X-band microwave amplifier and a driving coupler. This oscillator must be stable in terms of nominal frequency delivered. In addition, its elements must be less sensitive to environmental and mechanical disturbances. Compactness is evaluated in terms of efficiency and the signal is characterized in terms of power delivered and stability of the nominal frequency. We rely on the measurement of phase noise carried out using a bench developed in the laboratory [4] and we give an approximation of the specifications measured according modern appproach [5], by enriching the work done on the oscillators [6, 7].

2. MATERIALS AND METHODS
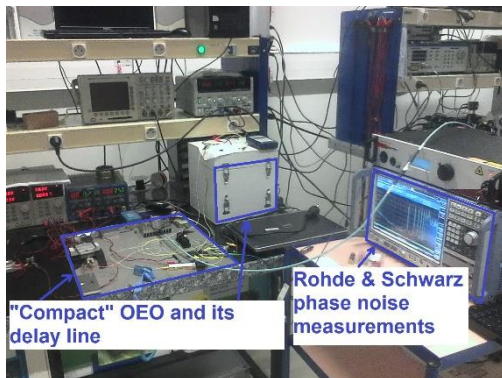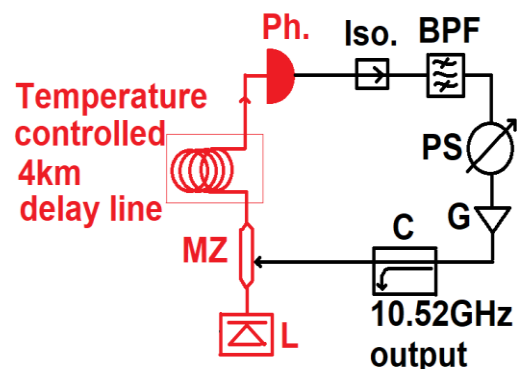
Fig. 1. (a) Picture of the optoelectronic oscillator and the phase noise measurement commercial bench. (b) OEO: Optical and electrical elements are drawn in red and black colors, respectively. L—laser; MZ—Mach Zehnder modulator; Ph—photodetector; Iso—isolator; BPF—band pass filter; PS—phase shifter; G— microwave low noise amplifier; C—coupler.

This work is derived from reference [4]. We describe here the Device Under Test (DUT). It is an Opto-electronic oscillator (OEO) for being miniaturized in a 1 litter volume. One litter is typically the volume for on-board [8]. If this oscillator had a delay line, this goal of miniaturization would be too ambitious. However, the compactness of the element comprising the delay lines could be achieved by packaging a coil of fiber, as is done for gyroscopes [9]. For the other building blocks of the delay line based OEO, compactness is ensured with patient 3D work on the OEO by interweaving the various components like the laser, modulator, and amplifiers, and providing compact power supply boards. The procedure follow here in the laboratory was not focused on compactness at this stage of the study. The compactness lead to other constraints, such as controlling the sensitivity of electromagnetism (EMC), which, in the case of an OEO, would be less impacted thanks to the optical aspect of a large part of the oscillation loop. Amplifiers and electrical components, on the other hand, are sensitive to EMC. It is not necessary to control optical fiber in terms of temperature, while the laser is stabilized of by a feedback loop [10].

For the OEO on the table, it delivered an output signal of 5 dBm at 10.52 GHz. It is constituted a RIO laser, model ORION driven by a 125 mA signal. Modulator is with an 11 GHz bandwidth, then, a 4 km optical fiber delay line, and a DSC40S Discovery photo-detector. In the electrical part of the loop of the oscillator, there is a 54 dB gain amplifier for the microwave signal, an X-band filter, an ARRA passive phase shifter, and a buffer amplifier (AML812-1901) at the lateral arm of a microwave coupler in order to extract the output microwave signal. The OEO is represented in Figure 1b. To adjust the gain of the microwave amplifier in the OEO oscillation loop, we proceed with a vector network analyser (VNA).

This OEO is given in Figure 1. Here, we have a photography of the OEO and the measurement bench, which served to characterize it. It is necessary to carry out this gain adjustment by working in an open loop.

It is easy to understand that the losses in the delay lines and all of the optical devices also needed to be compensated in order to ensure the continuity of the oscillation phenomenon over time [11]. We need to know the reflectance of each amplifier, as well as the noise factor, especially at the start of the amplification chain. Figure 1a shows a picture of the OEO during measurements and Figure 1b describes the OEO. As mentioned previously, there are two ways to evaluate the performance of the DUT in terms of phase noise. Prior to the measurement, we calibrated the two systems with a commercial frequency synthesizer (Anritsu/Wiltron 69000B) with a declared phase noise of -105 dBc/Hz at 10 kHz of a 10 GHz carrier [12]. The results are shown in section "Result on the measurement of a known frequency synthesizer". Figure 2 shows the setup of this measurement.
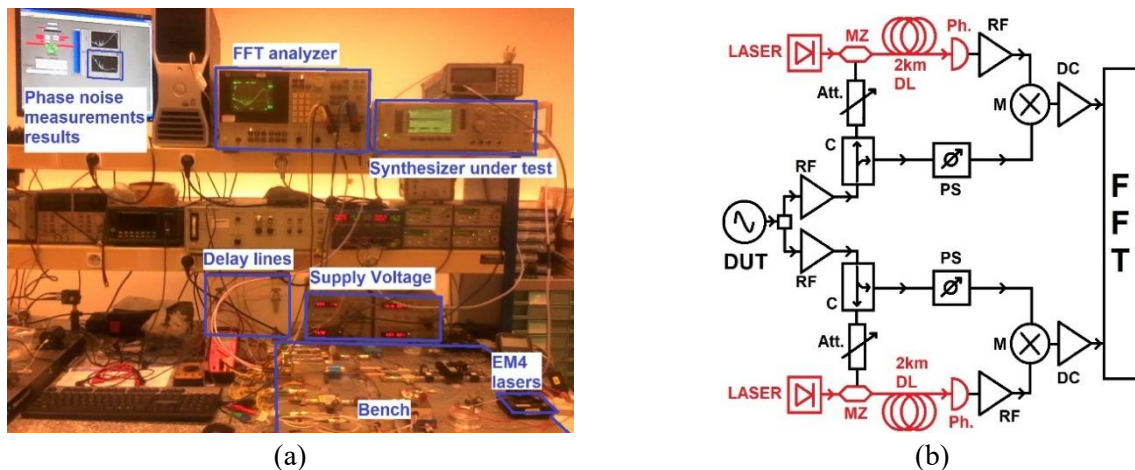
	(a)		(b)

Fig. 2. (a) Photo of the phase noise measurement bench developed at the laboratory while measuring the phase noise of a synthesizer under test. (b) Schematic view of phase noise measurement bench system using a double optical delay line. Optical elements and electrical elements are respectively drawn in red and black colors. DUT—device under test; MZ—Mach–Zenher modulator; DL—delay line; Ph—photodetector; M—mixer; DC—DC amplifier; RF—microwave amplifier; Att.—attenuator; C—directive coupler; PS—phase shifter; FFT—fast Fourier transform analyzer.

3. UNCERTAINTY ESTIMATION

Investigating the uncertainty calculation is an old challenge of scientists working on phase noise. It firstly concerns the knowledge of the experimentally determined phase noise. It is taken close to the carrier with a negative slope of S'(f) versus the Fourier frequency noted f. Secondly, it concerns the determination of the ground noise f_0 far from the carrier, mostly dependent from the power inside the loop with an approximation of kT/P, where k is the Boltzmann constant, T is the temperature, and P is the power. FredWalls and his colleagues from NIST described the principle of phase noise and its calculation [13, 14]. In 2010, Won Kyu Lee from Korea explained their work concerning uncertainty calculation [15]. In 2013, sources of uncertainties were discussed by Shinya Yanagimachi and his colleagues from Japan [16]. Several phase noise measurement techniques were investigated by Ulrich L. Rohde and Ajay K. Poddar from Germany in 2013 [17]. We proceed similarly for uncertainty calculation like in the case of a purely microwave setup [6]. The uncertainty is given accordingly to main guideline of the Bureau International des Poids et Mesures (BIPM) in the guide "Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement" [18]. Actually, we followed a modern approach to express uncertainty in measurement [5, 7, 19 – 22]. The uncertainty in the results of a measurement consist of several components, which may be listed as two categories according to the way in which their numerical value is estimated.

It is interesting to consider how the elementary terms are grouped together for the calculation of the final uncertainty. We can see that we are dealing with two main categories of elementary uncertainty terms. The first category of terms of uncertainty is called "type A". These terms are evaluated by statistical methods such as reproducibility, repeatability, special consideration about Fast Fourier Transform analysis, and the experimental standard deviation. The components in category A are characterized by the estimated variances. The second family of uncertainty contributions are evaluated by other means. They are called "type B", and because various components and temperature control, experience with or general knowledge of the behaviour and properties of relevant materials and instruments, manufacturer's specifications, data provided in calibration and other certificates (noted BR), their uncertainties assigned to reference data taken from handbooks. The components in category B should be characterized by quantities, which may be considered as approximations to the corresponding variances, the existence of which is assumed.

We are getting to the significant part about uncertainties. We must now examine each of the elementary terms. 4.1. Statistical Contributions

Repeatability (A1): It is the variation in measurements obtained by one person on the same item and under the same conditions. Repeatability conditions include the same measurement procedure, the same observer, and the same measuring instrument used under the same conditions, repetition over a short period of time, and at the same location. We automatically performed 4 to 10 measurements with the fast Fourier transform (FFT) analyzer. The elementary term of uncertainty for repeatability eRep was experimentally found to be equal to 0.3 dB for 4 measurements and 0.2 dB for 10 measurements at 1. Its probability distribution was normal (Gaussian). A1 was thus deduced with a 0.682 at 1 (where is the standard deviation).

Reproducibility (A2): Measurements are performed by the same operator. There are no changes caused by differences in the operator behavior. All components and devices are dedicated to the instrument and none of them are replaced. This term was selected as zero. Finally, statistical contribution can be considered as follows: A =p (SAi) (i).

We can list the different categories of elementary uncertainty terms in table 1.

Note that the individual contribution of each elementary terms strongly depends on the shape of their diffusion law. For the terms of types A, we logically have shapes according to the Gaussian law. However, this is not always true for other terms. For example, among the terms of type B, some will follow the normal distribution, others the triangular distribution. Uncertainty at a 1 σ interval of confidence is calculated as follows: $u_c = \sqrt{(A^2 + BR^2 + BL^2)}$ (ii)

According to Equation (i), it can then be considered that the whole statistical contribution is better than 0.69 dB. We deduce from (ii) that the uncertainty at 1 sigma, noted as u_c, is better than $\sqrt{(0.69^2 + 0.20^2)}$ dB. Its leads to a global uncertainty of ± 0.72 dB at 1 σ.

Table 1. Typical chart used for uncertainty evaluation

Uncertainty elementary terms	Designation
A-type example	Repeatability
A-type example	Reproducibility
A-type example	Uncertainty term due to the number of sample
Intermediary result on statistical elementary terms	$(\Sigma Ai^2)^{1/2}$
B-type first category	BR (related to Standards)
B-type second category	BL1
B-type second category	…
B-type second category	BLn
Intermediary result	ΣBLi
Total uncertainty estimated at 1 sigma	$(A^2+BR^2+BL^2)^{1/2}$

Table 1. Typical chart for estimation of the uncertainty

For convenience and to keep an operational uncertainty in case of the degradation or drift of any elementary terms of uncertainty, it is wise to degrade the global uncertainty. This is why we choose to keep U = ±2 dB at 2 σ for a common use of the phase noise optoelectronic instrument, instead of ±1.44 dB at 2 σ. This final uncertainty is defined at 2 σ, according to the empirical rule 68.27% at 1 σ is not enough, but 95.45% at 2 σ is more efficient for a normal distribution in statistics.

4. CONCLUSION

In conclusion of this paper, we can indicate that we have characterized the OEO in terms of phase noise. The signal delivered at 10.52 GHz with an output power of 5 dBm presents a relatively good performance in terms of phase noise, with a minimum of −145 dBc/Hz at 3×10^4 Hz from the carrier. The associated uncertainty is better than ±2 dB at 2 σ. This re-sult is encouraging for an OEO produced on a table, and which, can potentially be rear-ranged into a compact prototype that fits in a volume of one litter.

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