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Optoelectronic phase noise system designed for microwaves photonics sources measurements in metrology application

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ABSTRACT

The performance advances in communication systems like Radar system, precision navigation, space application and time and frequency metrology require more stable frequency and low phase noise system. Here is presented a configuration of phase noise measurement system operating in X- band using a photonic delay line as a frequency discriminator. This system doesn't need any excellent frequency reference and works for any frequency between 8.2 and 12.4 GHz. Using cross correlation on 500 averages, noise floor of the instrument is respectively -150 and -170 dBc/Hz at 10^1 and 10^4 Hz from the 10 GHz carrier (-90 and -170 dBc/Hz including 2 km delay lines). This instrument is developed in the context of association with the national french metrology institute (laboratoire national de métrologie et d'essais, LNE). This calibration system is to be integrated in measurements means of the accredited laboratory to improve the Calibration Metrology Capabilities (CMC) of the LNE.

Keywords: Optoelectronic, phase noise, metrology, X-band, microwaves, photonic delay line, Calibration Metrology capabilities

1. INTRODUCTION

Radio frequency [1, 2, 3] or microwaves oscillators or optoelectronic oscillators with fiber delay line [4, 5] and their further development with optical resonators [6, 7, 8, 9], and cryogenic sapphire oscillators [10] can all present interesting performances with ultra-stable signals in short term domain characterized by a low phase noise. A convenient method is to lock the oscillator to be measured on a reference standard [11, 12, 13]. However it is only possible to determine the phase noise for oscillators compared to another one with the same frequency if noise is expected to be better than a synthesizer. That's why there is a need to develop methods based on the use of two delay lines and cross correlation to be able to characterize an oscillator without referring to another one with the same delivered frequency. In this short paper is presented the development made on an instrument dedicated to such measurement for metrology applications.

2. BASIC CONCEPTS

A quasi-perfect RF-microwave sinusoidal signal can be written as :

$$v(t) = V_0 [1 + \alpha(t)] \cos(2\pi\nu_0 t + \varphi(t)) \quad (1)$$

where V_0 is the amplitude, ν_0 is the frequency, $\alpha(t)$ is the fractional amplitude fluctuation, and $\varphi(t)$ is the phase fluctuation. Equation (1) defines $\alpha(t)$ and $\varphi(t)$ in low noise conditions: $|\alpha(t)| \ll 1$ and $|\varphi(t)| \ll 1$.

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Short-term instabilities of signal are usually characterized in terms of the single sideband noise spectral density PSD $S(f)$. S is typically expressed in units of decibels below the carrier per hertz (dBc/Hz) and is defined as the ratio between the one-side-band noise power in 1 Hz bandwidth and the carrier power:

$$\mathcal{L}(f) = \frac{1}{2} S_{\phi}(f) \tag{2}$$

This definition includes the effect of both amplitude and phase fluctuations. However, the amplitude and phase noise have to be known separately because they act differently in the circuit. For example, the effect of amplitude noise can be reduced by amplitude limiting mechanism and mainly suppressed by using a saturated amplifier. Phase noise of microwave oscillators can usually be characterized by heterodyne measurement. Whereas, for such a system, we need a reference oscillator operating exactly at the frequency of the device under test (DUT) with lower phase noise. Any reference is required for homodyne measurement with delay line discriminator [13, 14, 15]. At microwave frequencies electrical delay is not suitable because of its high losses. However photonic delay line offers high delay and low attenuation equal to 0.2 dB/km at $\lambda=1.55 \mu\text{m}$.

Optoelectronic phase noise measurement system [13, 14, 15] is schematically represented on Fig. 1. It consists on two equal and fully independent channels. The phase noise of the oscillator is determined by comparing phase of the transmitted signal to a delayed replica through optical delay using a mixer. It converts the phase fluctuations into voltage fluctuations. An electro-optic modulator allows modulation of the optical carrier at microwave frequency. The length of the short branch where microwave signal is propagating is negligible compared to the optical delay line. Mixers are used as phase detectors with both saturate inputs in order to reduce the amplitude noise contribution. The low pass filters are used to eliminate high frequency contribution of the mixer output signal. DC amplifiers are low flicker noise.

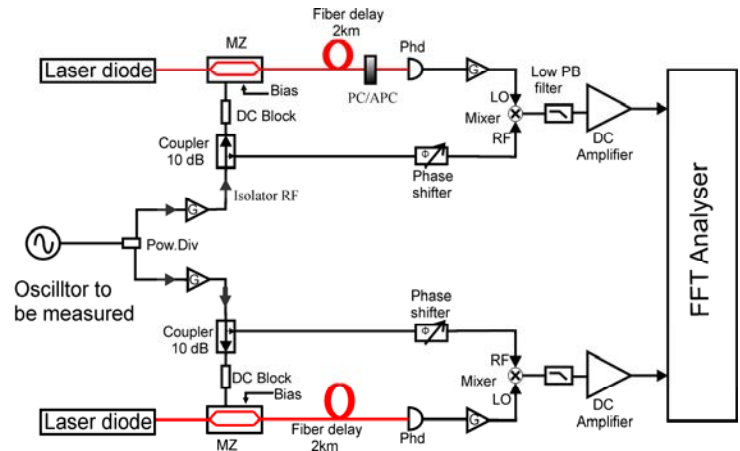


Figure 1. Phase noise bench.

The oscillator frequency fluctuation is converted to phase frequency fluctuation through the delay line. If the mixer voltage gain coefficient is K_{ϕ} (volts/radian), then mixer output rms voltage can be expressed as [14] :

$$V_{out}^2(f) = K_{\phi}^2 \cdot |H_{\phi}(jf)|^2 \cdot S_{\phi}(f) \tag{3}$$

Where $|H_{\phi}(jf)|^2 = 4 \sin^2(\pi f \tau)$ is the transfer function of optical delay line, and f is the offset frequency from the microwave carrier. The Eq. (3) shows that the sensitivity of the bench depends directly on K_{ϕ}^2 and $|H_{\phi}(jf)|$. The first is related to the mixer and the second essentially depends on the delay τ . The maximum measurement bandwidth is practically set to $0.95/\tau$ [14], so the choice of an appropriate delay is so important. Several measurements [14] shows that $\tau = 10\mu\text{s}$ give a good agreement between bandwidth and sensitivity.

In practice, an FFT analyzer is needed to measure the spectral density of noise amplitude $V_{out}^2(f)/B$, where B is the bandwidth used to calculate $V_{out}(f)/B$. The phase noise of the DUT is finally defined by Eq. (4) and taking into count the gain of DC amplifier G_{DC} as :

$$\mathcal{L}(f) = \frac{S_{\varphi}(f)}{2} = \frac{V_{\text{out}}^2(f)}{2K_{\varphi}^2|H_{\varphi}(jf)|^2} \frac{1}{G_{\text{dc}}^2} \frac{1}{B} \quad (4)$$

3. RESULTS AND INTERPRETATION

The measured phase noise includes the DUT noise and the instrument background. The cross correlation method allows to decrease the cross spectrum terms of uncommon phase noise as $\sqrt{1/m}$, where m is the average number. Thereby uncorrelated noise is removed [13, 14] and sensitivity of measure is improved.

To validate the measure of our phase noise bench, we need to compare datasheet of the commercial frequency synthesizer Anritsu/Wiltron 69000B with the phase noise we measure using our system.

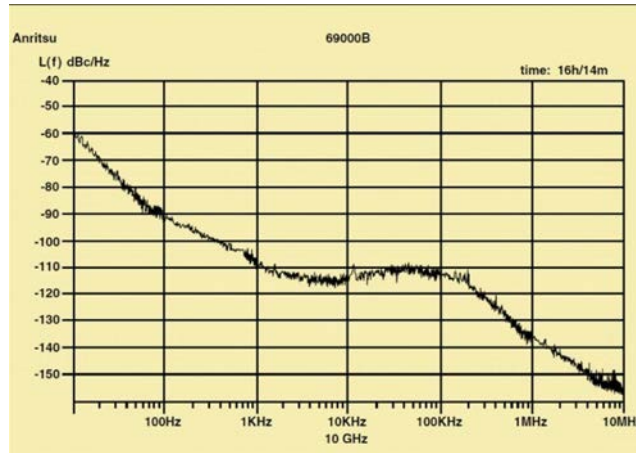


Figure 2. Datasheet of 10 GHz phase noise of commercial Anritsu 69000B series synthesizer.

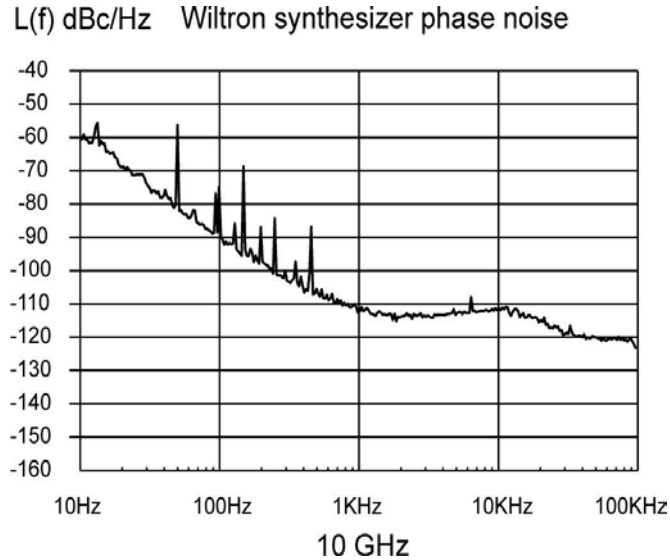


Figure 3. Phase noise of the commercial synthesizer measured with our bench with $K_{\varphi} = 425$ mV/rad and $G_{\text{DC}} = 40$ dB.

The Fig. 3 shows the result of this measure. We can see that our bandwidth is limited to 100 kHz ($\tau = 10 \mu\text{s}$) and the measured phase noise corresponds to the datasheet on Fig. 2.

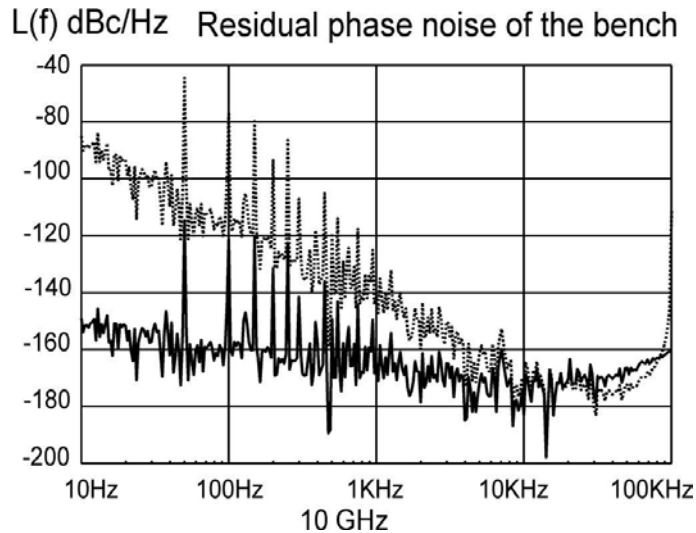


Figure 4. Phase noise floor of the bench measured with Anritsu synthesizer (500 averages).

Fig. 4 represents the background phase noise of the bench after performing 500 averaged with cross-correlation method, when removing the 2 km optical delay line. In this case, phase noise of the 10 GHz synthesizer is rejected. The solid curve shows noise floor (without optical transfer function) respectively better than -150 and -170 dBc/Hz at 101 and 104 Hz from the 10 GHz carrier. Dotted curve is the noise floor when optical fiber is introduced.

4. EVALUATION OF THE UNCERTAINTY

There are two categories of uncertainties terms [15] : the first category is called "type A", statistic contribution such as reproducibility, repeatability, special consideration about Fast Fourier Transform analysis, and the experimental standard deviation. Second family of uncertainties contributions is "type B" and due to various components and temperature control, but also to the asymmetry of the instrument. Experience with or general knowledge of the behavior and properties of relevant materials and instruments, manufacturer's specifications, data provided in calibration and other certificates, uncertainties assigned to reference data taken from handbooks. By the way, uncertainty on $\mathcal{L}(f)$ strongly depends on propagation of uncertainties through the transfer function as deduced from equation (4). Global uncertainty is strongly related to repeatability of the measurements. Repeatability 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, the same measuring instrument, used under the same conditions, repetition over a short period of time, the same location. We switch on all the components of the instrument and perform a measurement keeping the data of the curve. Then we need to switch them off and switch them on again to obtain another curve. We must repeat this action several times until we have ten curves. Elementary term of uncertainty for repeatability is found to be equal to 0.68 dB. Other elementary terms still have lower contributions. For instance, temperature effects, resolution of instruments or uncertainty on the determination of the coefficient K_ϕ are lower. Its leads to a global uncertainty of 1.58 dB [16].

5. CONCLUSION

Performances and first consideration about estimation of the uncertainty was a bit detailed in this paper to show the main advantage of the instrument developed for metrology applications. With high performance better than -150 dBc/Hz at 10 Hz from the 10 GHz carrier, integration in the mean of the accredited laboratory is expected and the new field of capabilities in terms of calibration of single source in X-band will be soon achieved in order to extend the CMC of the LNE.

6. ACKNOWLEDGEMENTS

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