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Realization of a Phase Noise Measurement Bench Using Cross Correlation and Double Optical Delay Line

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In this paper there are presented first results obtained with a phase noise measurement bench operating in X-band, realized in our laboratory, using double optical delay line and cross correlation. Phase noise floor using a microwave sapphire oscillator is better than –160 dB rad^2/Hz at 10 kHz from the 10 GHz carrier, using a 2 km optical delay line.

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1. Introduction

The aim of this work consists in an exploratory approach of potential performances of phase noise measurements bench using cross correlation and double optical delay line [1] in order to measure the phase noise of microwaves sources and optoelectronic oscillators [2]. We first developed a bench without any cross correlation in order to optimize its intrinsic noise floor and then we proceeded with a fast Fourier transform (FFT) analyzer that has two inputs. Results are described further in this paper.

2. First approach with a simple optoelectronic bench

We first developed and tested a first version of this bench without any cross correlation with a microwave synthesizer. Measurements bench's noise floor was

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characterized by suppressing the delay line. Several low noise photodiodes with or without integrated amplifiers were tested. Synthesizer was replaced by a sapphire oscillator to reduce the amplitude noise of the source. One of the advantage of this kind of source is the low amplitude noise it delivers. Sapphire oscillator is constituted by a sapphire resonator, a 30 dB amplifier with its isolators, a 10 dB coupler, a phase shifter and a band pass filter. The power delivered is about 10 dB m. We have chosen a laser diode with a low relative intensity noise (RIN) about –155 dB/Hz as the optical carrier used to uncorrelate the RF signal from the device under test (DUT). Noise floor was considerably reduced down to –145 dB rad^2/Hz at 10 kHz, from the 10 GHz RF carrier modulating the signal delivered by the laser diode, by being introduced in the loop from the DUT. It shows that the AM noise of the 1.3 μm laser is one of the main limiting parameter in our bench. Optical fiber are then inserted in our system as delay lines to make uncorrelated the two arms at the input of the mixer, and measure the noise floor of the source to be characterized. Principle is given on Fig. 1.

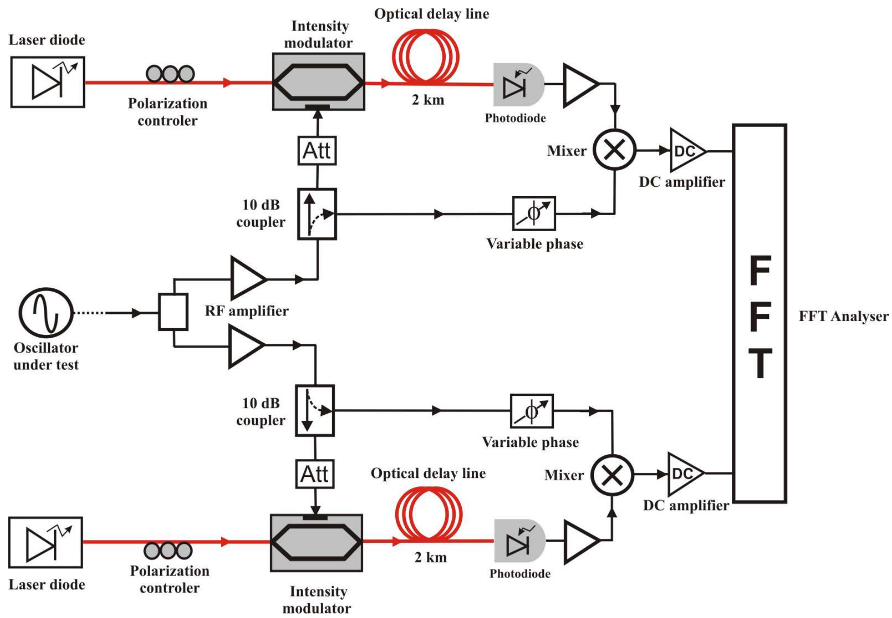

Fig. 1. Principle of the phase noise measurement bench system using a double optical delay line.

A 2 km delay line corresponds to a delay of $\tau = 10$ μs. This delay allows the measurement of the phase noise of the oscillator placed at the input of our bench. It is obtained by using the relation between the measured spectral density of phase noise $S_{\varphi\mathrm{FFT}}$ with the FFT analyzer and the phase noise of the oscillator $S_{\varphi\mathrm{osc}}$ that are related by the following expression:

$$S_{\varphi \mathrm{osc}} = S_{\varphi \mathrm{FFT}} - 20\log(2\sin(\pi f \tau)). \tag{i}$$

This formula allows to express the phase noise of the oscillator to be measured versus the phase noise obtained with the FFT analyzer corrected by the optical fiber transfer function.

The sensitivity of the bench increases with the length of the delay line, but the cutoff frequency decreases as the band pass drops from a 100 kHz Fourier frequency for the 2 km delay line, to a 50 kHz for a 4 km. If we want to characterize a microwave source above a 100 kHz Fourier frequency from the carrier, we can hold a fiber that is shorter: it will provide a cutoff frequency beyond 100 kHz. But on the other hand, sensitivity of our system will be deeply degraded in the range 0 to 100 kHz from the carrier, if there is a small optical delay. That is why the ability to commute two lines with different length could help to characterize sources on a larger Fourier frequency interval around the carrier.

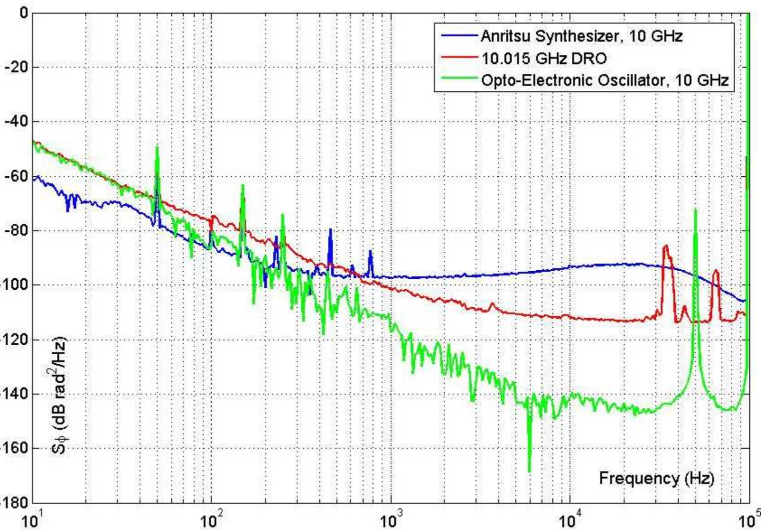

Fig. 2. Phase noise measurement in X-band of an Anritsu microwave synthesizer, a DRO and an optoelectronic oscillator.

We first measured the phase noise of an Anritsu synthesizer, type 69000. Our result corresponds to the data sheet of this microwave synthesizer, that contributes to validate our experimental result. We also operate with an optoelectronic oscillator developed in the laboratory and with a dielectric resonator oscillator (DRO). The obtained results are reported in Fig. 2. Then we characterized another source: a sapphire oscillator developed in the laboratory. The principal advantage is that we do not need any reference oscillator to operate with our bench.

Another advantage of this system is that it operates in the 8 to 12 GHz frequency band and so we can characterize any oscillator in this band. Phase noise floor is not the same in the whole X-band. To solve this problem, we try to

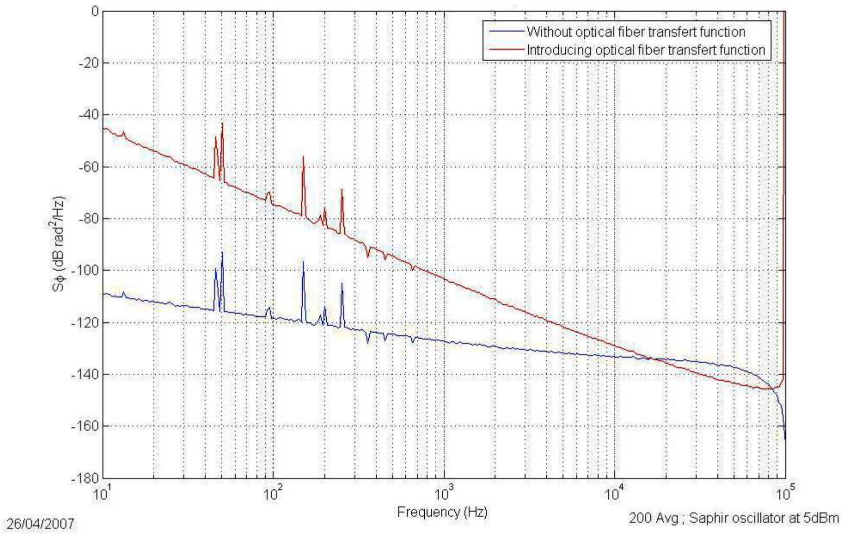

Fig. 3. Phase noise measurement of a sapphire oscillator.

saturate the amplifier at the input of our bench in order to limit the AM noise of the synthesizer and to have a uniform response for all operating frequencies. Effect of AM noise has been studied previously [3]. In Fig. 3, the phase noise without optical fiber transfer function is in blue. We introduced the optical transfer function to get the noise of the sapphire oscillator given in red curve in Fig. 3. The peak at 100 kHz from the carrier corresponds to the 10 μs delay due to the length of the optical delay line. The delay line theory is described in a previous work [1].

3. Results with the bench using double optical delay line and cross correlation

The noise floor was reduced by making inter-correlation bench. Phase noise floor curve is given on Fig. 4. The signal delivered by the source to be characterized is divided in two branches and then, two similar parallel benches as developed in the first part of our work. It allows the different noises from the devices in each bench, to become uncorrelated. Then the noise floor can be considerably reduced by performing averaging of incoherent sources. Noise floor is then reduced of β (expressed in dB) proportional to the m, number of averaging made as follows:

$$\beta = 10\log(1/\sqrt{2}m). \tag{ii}$$

Thus, obtained results using 2 km optical fibers delay lines and performing inter-correlation on 200 averaged, give a noise floor which is –160 dB rad^2/Hz at 10 kHz from the 10 GHz carrier. Next to this 10 GHz carrier, we measured –110 dB rad^2/Hz at 100 Hz.

These levels can be improved by increasing the number of averaging and the length of the delay line. Actually, with a FFT analyzer with dual input like the

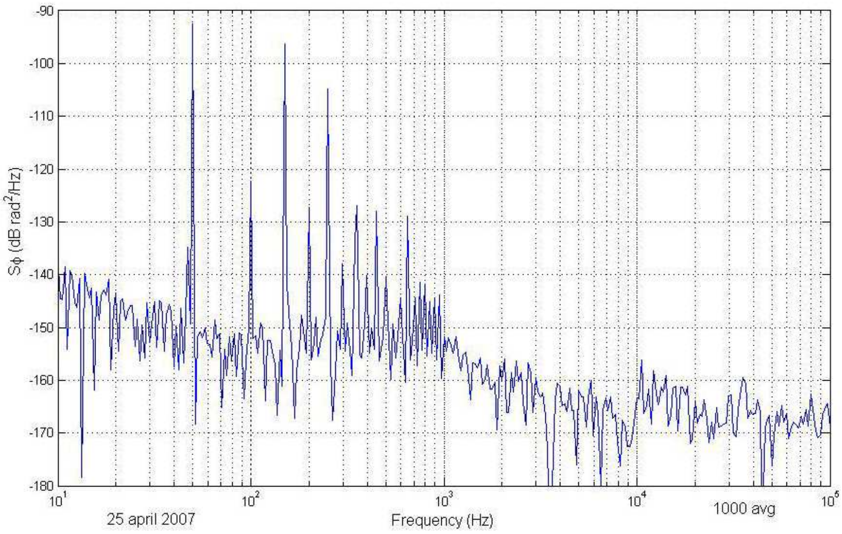

Fig. 4. Phase noise floor of the bench measured with sapphire oscillator.

HP3562A type, uncorrelated noise added by different components are averaged by inter-correlation following the previous relation (ii). A 200 average measure takes approximately 20 min. For a 500 average measure, it takes 45 min and the obtained noise floor only decreases from −163 to −165 dB rad^2/Hz.

4. Conclusion and further work

In this work, we have performed and characterized an optoelectronic system for phase noise measurements with different optical delay lines. Characterization of a known commercial synthesizer helped to validate results given by our bench. Phase noise floor using a microwave sapphire oscillator is better than −160 dB rad^2/Hz at 10 kHz from the 10 GHz carrier, using a 2 km optical delay line. We still have to realize the commutation between several delay lines. We can notice that the optical channels enable electric and magnetic isolation and ground isolation and provides the ultimate shielding.

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